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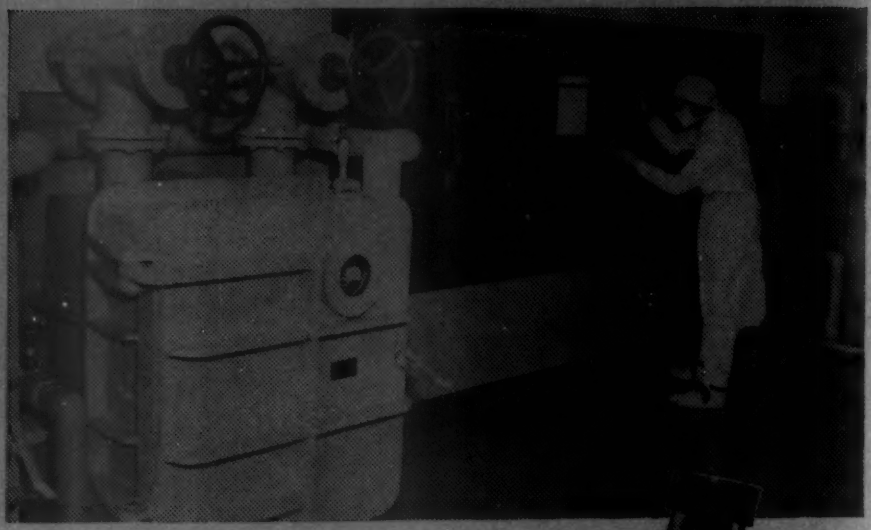

Penicillin-drying room at plant of Charles Pfizer & Co., Inc., makers of fine chemicals in Brooklyn. Micromax Recorder, in center of control panel, shows temperature of water in shelves of dryers.

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STUDIES IN THE SENSITIVITY OF PHOTOGRAPHIC MATERIALS. III. INTRINSIC SENSITIVITY.

BY

A. P. H. TRIVELLI.

Communication No. 1057 from the Kodak Research Laboratories.

INTRODUCTION.

A theory of the production of an image in an assemblage of light-sensitive grains was offered by Silberstein.[1] This theory has been confirmed by the quantitative agreement found between several hundred calculated and observed characteristic curves. It does not, however, furnish a picture of the atomic mechanism of the formation of a latent image. Such an explanation is not a requirement for the support of a theory. It is of greater importance to determine the conditions under which an event occurs than to try to explain it. In other words, the accurate knowledge of a fact goes above its explanation. It is wrong to reject a well-established fact simply because it is inexplicable. The significance of the fact that only a small part of the energy absorbed by the exposed grain is sufficient to make it developable lies in the fact that it is a reproducible and measurable occurrence in latent-image formation. It indicates that there is a distinct difference between the photolytic action and the latent-image formation in an exposed silver halide grain. The idea that the latent-image formation is the initial stage of the photolytic decomposition of the silver halide of the grain is not entirely true. The quantum theory of exposure brings out the fact that while the photolytic action by exposure may take place over the whole grain, latent-image formation is restricted to a certain part of the grain. Therefore, the sensitivity related to photochemical reactions has another meaning than the sensitivity related to latent-image formation. In this paper we are dealing exclusively with the latter one.

[1] L. Silberstein, *Phil. Mag.*, **44**, 257 (1922); *Ibid.*, **45**, 1062 (1923); *Ibid.*, **50**, 464 (1928); *J. Opt. Soc. Amer.*, **28**, 441 (1938); *Ibid.*, **31**, 343 (1941); *Ibid.*, **35**, 93 (1945).

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

GENERAL DISCUSSION OF SENSITIVITY.

There is no definition of the sensitivity of a photographic emulsion layer in the literature which is generally accepted. However, all methods of measuring sensitivity arrive at this same result, namely, sensitivity is always expressed as a pure number and all names applied to it are only qualifications of the particular method used, to distinguish it from other methods.

In the first paper of this series, the author [2] pointed out that the sensitivity of a photographic emulsion layer is complex. To regard sensitivity only as a reciprocal value of the exposure necessary to produce a certain chosen density or as the number of absorbed quanta

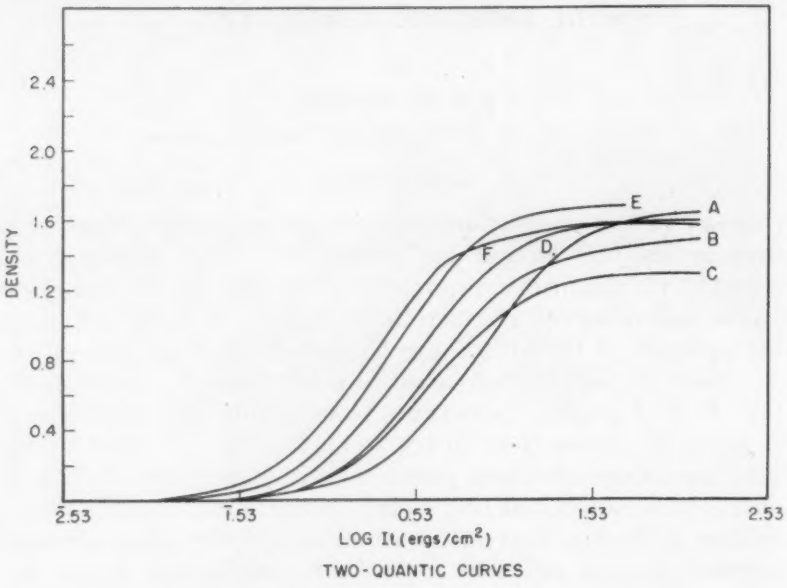

FIG. 1.

necessary to make a grain developable is an inadequate expression of sensitivity, which leads to erroneous conclusions.

Sensitivity is of a dualistic nature. This dualism is not reduced to a monistic concept by making it incomplete. The dual nature of sensitivity is well known in the Hurter and Driffield empirical system of sensitivity as "inertia speed" and "gamma." In Jones's pragmatic system of sensitivity, it is called "gradient speed" and "average gradient." In Silberstein's quantum theory of exposure, it is called the "intrinsic sensitivity" (ϵ) and the "quantum number" (r).

The quantum number represents the *minimum* number of absorbed quanta required to make a grain developable. These quanta are

[2] A. P. H. Trivelli, J. FRANKLIN INST., 239, 269 (1945).

called "effective quanta." Their number, r, determines the shape of the characteristic curve. The intrinsic sensitivity, ϵ, represents the probability that a grain will absorb the number of effective quanta required to produce developability at a certain exposure. It is related to the quantum number, r, in such a way that, for example, the probability of grains' becoming developable with four quanta is equal to half the probability of grains' becoming developable with two quanta.

Although ϵ and r are interrelated in a simple way, sensitizing sometimes shows complex effects. For instance, the intrinsic sensitivity of the grain may be affected without changing the quantum number of the emulsion layer.

This is shown in Fig. 1, which consists of six two-quantic characteristic curves, *A*, *B*, *C*, *D*, *E*, and *F*, obtained from an emulsion which was sensitized with six different gelatins. Sensitometric exposures were made of wavelength $\lambda = 426$ mμ. They were plotted graphically with an exposure axis in ergs per square centimeter of surface of the

TABLE I.

Sensitometric Characteristics of Six Different 2-Quantic Curves.

Emulsion	Developer	t_d in min.	γ	D_{max}	γ/D_{max}	$1/i$	$\epsilon \times 10^4$
A	DK-50	12	1.35	1.63	0.828	0.54	0.46
B	DK-50	12	1.31	1.48	0.885	0.89	1.43
C	FeOX	9	1.16	1.28	0.906	0.89	1.46
D	DK-50	8	1.33	1.59	0.836	1.23	1.76
E	FeOX	18	1.47	1.67	0.880	1.55	2.34
F	FeOX	18	1.44	1.56	0.923	1.95	3.10

light-sensitive material. Development was carried out under thermostatic control in DK-50 or ferrous-oxalate (FeOX) developer with vigorous stirring for t_d minutes at 20° C.

From theoretical considerations Silberstein postulated that simple two-quantic curves occur approximately between the values of γ/D_{max} equal to 0.773 and 0.909. In Table I are given the measured gamma, γ, and the values of D_{max} and γ/D_{max} of the different curves, together with the reciprocal values of the inertia points, i, of the curves, for comparison with the values of $\epsilon \times 10^4$.

These measurements were obtained from fog-corrected curves.

To regard all photographic materials with the same quantum number as having the same sensitivity is, therefore, just as erroneous as to consider that all photographic films with the same gamma have the same sensitivity.

The effect of sensitizing can be studied by quantitative comparison of the values obtained before and after treatment of the photographic emulsion. Figure 2 shows such a comparison with two characteristic curves, *A* and *B*, for two emulsions which were coated on film to equal

thicknesses and under the same conditions. Curve *A* was obtained from an unsensitized silver bromide emulsion with sensitometric exposures of wavelength $\lambda = 426$ mμ, developed 5 minutes in DK-50 developer at a thermostatically controlled temperature of 20° C. Curve *B* was produced in the same way from the same emulsion by sensitizing. Both curves represent the observed values. The calculated densities for the different exposures according to the quantum theory of exposure are indicated by circles and crosses in the figure. The data agree very

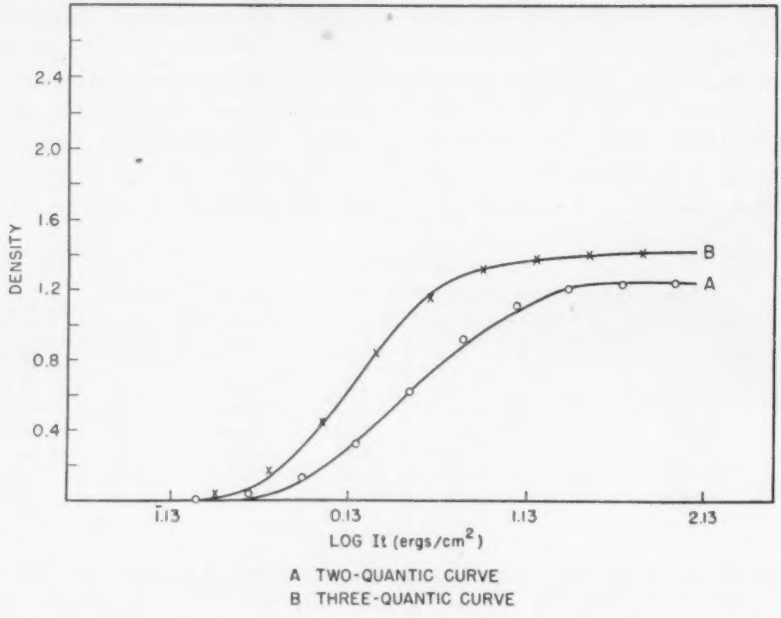

FIG. 2.

well with the observed densities. Curve *A* is a two-quantic, and Curve *B*, a three-quantic one.

When Hurter and Driffield's system is used, this sensitizing increases the reciprocal value of the inertia point from 1.55 (Curve *A*) to 2.25 (Curve *B*) and the gamma from 0.96 (Curve *A*) to 1.32 (Curve *B*). Everyone would recognize this as a definite sensitivity increase. However, this sensitometric system is an empirical one, giving incomplete information about sensitivity. The quantum theory of exposure gives more information. According to this theory, the sensitizer has increased the value of ϵ from 1.88×10^{-4} (Curve *A*) to 5.84×10^{-4} (Curve *B*) and has *desensitized* the emulsion layer from $r = 2$ quanta (Curve *A*) to $r = 3$ quanta (Curve *B*). Curve *B*, therefore, is the result of simultaneous sensitizing and desensitizing by the same sensitizer. To find numerically the effective sensitizing, the values of ϵ must

be compared with each other for characteristic curves having the same quantum number. This means that ϵ of Curve *B* must be reduced to two thirds of its value, which gives as the final result that the *effective sensitizing* is equal to $\frac{3.89}{1.88} = 2.07$.

THE INTRINSIC SENSITIVITY.

The sensitivities of the grains of a photographic emulsion can be measured by determining which grains become developable at maximum gamma development and which do not by the controlled exposure of a number of separate grains spread out in a single layer on an optically plane glass plate. Einstein's equivalence law indicates that the energy in a beam of light is discontinuously distributed, producing a discretely distributed quantic absorption by the grain.

Let us consider that there are grains of silver halide of equal size a (measured by their projective area in μ^2) lying in a plane and exposed to monochromatic blue radiation. Let the exposure be n quanta per unit area of the plane surface on which the grains are lying. That is to say, let n be the probable number of quanta incident upon a unit area; the probable number of quanta striking a grain will then be na. Some of these quanta will be reflected from the surface of the crystals, while others will pass through the grains, and the remainder,

$$\kappa na$$

quanta, will be absorbed. The absorption coefficient, κ, of the grain is of the order of several hundredths, depending upon the wavelength of the incident radiation. Eggert and Noddack [3] found, for instance, that with silver bromide grains for $\lambda = 436$ mμ, $\kappa = 0.10$, and for $\lambda = 365$ mμ, $\kappa = 0.20$.

The (probable) total number of quanta absorbed by the grain, κna ($< na$), produces the photochemical decomposition of the silver halide. However, the total number of absorbed quanta is not necessarily equal to the number of quanta which are sufficient to introduce developability of the grain. Let the probable number of quanta, which are *sufficient to introduce* developability of the grain, be

$$\epsilon na,$$

where $\epsilon < \kappa$. Let this be called the probable number of *efficient quanta*.

If there is no distinction between ϵ and κ, so that $\epsilon = \kappa$, then all absorbed quanta are active in the formation of the latent image. Whether or not this is true must be decided by experimental evidence. Suppose, for the simplest case, that every efficient quantum makes a

[3] J. Eggert and W. Noddack, *Die Naturwissenschaften*, **15**, 57 (1927).

grain developable. This means that one quantum is the minimum number of quanta required to introduce developability of a single grain. Then, at the exposure ϵna, k, out of an assemblage of N exposed grains, become developable. Silberstein [4] showed from Poisson's law that for different exposures in such a case the following equation can be derived:

$$k = N(1 - e^{-\epsilon na}). \tag{1}$$

From this equation it follows that

$$\epsilon = \frac{1}{an} \log \frac{N}{N - k}. \tag{2}$$

The only variables in these equations are the exposure, n (in quanta), and the number of developed grains, k. The values of a, ϵ, and N are constants. The right-hand symbols of Equation (2), N and k, can be counted, the size a can be measured microscopically, and the exposure n can be determined. Therefore, in Equation (2), ϵ *is a directly measurable pure number.*

The same thing holds true if at least 2, 3, $\cdots$, r quanta are necessary to make a grain developable. Only Equations (1) and (2) become more complicated.

Whatever the interpretation of ϵ may be, the value of this number has been found consistently to be *much smaller* than the absorption κ. In fact it has been found in different emulsions to be of the order:

$$\epsilon = z \times 10^{-5},$$

in which the number z varies between a fraction of one and 60 or 70.

By reinvestigation of old experimental data of one-grain-layer emulsion coatings on optically plane glass plates in the light of our present greater knowledge of the quantum theory of exposure, it has been found, for instance, that for the Seed Lantern emulsion exposed to radiation of wavelength $\lambda = 426$ mμ, $\epsilon = 0.39 \times 10^{-5}$. For an experimental emulsion, W12C, exposed to radiation of wavelength $\lambda = 470$ mμ, it was found in the same way that $\epsilon = 1.2 \times 10^{-5}$; and for a Seed Graflex emulsion with the same exposure, the value of $\epsilon = 33 \times 10^{-5}$. It was also found that with increasing grain size the value of ϵ increases also.

This is experimental evidence that only a small part of the absorbed quanta is used for latent-image formation.

Therefore, the intrinsic sensitivity of a silver halide grain is not measured by its total absorption coefficient, but by its effective absorption.

It has been mentioned that ϵ stays constant for different exposures of equal grain sizes. This holds true also for the average grain size,

[4] L. Silberstein, *Phil. Mag.*, **44**, 257 (1922).

$\bar{a}$ in μ^2, of an emulsion with different grain sizes. In such cases, the shape of the size-frequency curves must be taken into account. We are then dealing with an average value of $\epsilon\bar{a}$. If the emulsion is coated in multigrain-layer thicknesses, the gradual light absorption in the emulsion layer has to be considered.

For the exposure,

$$y = \epsilon\bar{a}n, \tag{3}$$

Silberstein [4] derived the following equation:

$$\frac{D}{D_{\max}} = \frac{y^r(r + 1 + y)}{(1 + y)^{r+1}}, \tag{4}$$

in which D and n are variables and r, $D_{\max}$, ϵ, and $\bar{a}$ are constants. For Curve A of Fig. 2, for instance, which is two-quantic, Equation (4) becomes

$$\frac{D}{D_{\max}} = \frac{y^2(3 + y)}{(1 + y)^3}. \tag{4a}$$

The average grain size of an emulsion having this characteristic curve, A, is $\bar{a} = 0.82\ \mu^2$, for which the sensitivity was found to be $\epsilon = 1.88 \times 10^{-4}$. With $D_{\max}$ known, all the densities for the different exposures, expressed in log ergs per square centimeter of film surface, can be calculated, giving the densities tabulated in Table II, together with the deviations, ΔD, from the observed densities.

TABLE II.

Characteristic Curve A.

Log E	D_{obs}	D_{calc}	ΔD
$\bar{1}.87$	0.12	0.13	+ 0.01
0.17	0.34	0.32	− 0.02
0.47	0.62	0.62	0.00
0.77	0.88	0.92	+ 0.04
1.07	1.08	1.11	+ 0.03
1.37	1.21	1.20	− 0.01

The agreement between observed and calculated densities is good.

THE EXPLANATION OF SENSITIVITY.

Toy [5] showed that at a certain exposure not all grains with the same size and shape in a photographic emulsion become developable. This seemed to be the first direct evidence that grains of the same size have different sensitivities. The result has been confirmed experimentally by the investigations of one-grain-layer coatings in these Laboratories.

In the wave theory of exposure, the energy of a beam of light is carried by the amplitude of the wave, distributed as a continuum

[5] F. C. Toy, *Phot. J.*, **61**, 417 (1921).

through the whole space occupied by the light. It is, therefore, quite understandable that in this theory different sensitivities among grains of equal size were regarded as entirely due to differences in the structure and composition of the grains.

Although it is well known that the sensitivity of a grain varies with the wavelength and often with the intensity of the incident radiation, it does not afford evidence against the concept that sensitivity differences among grains of equal size and shape may also be due to the structure of the light.

In an investigation by Dr. Silberstein and the author,[6] of x-ray exposures on grains, a silver bromide emulsion was used, all of the grains of which, with the exception of the smallest ones, consisted of flat tablets of the same thickness. One-grain-layer coatings made with this emulsion were exposed in a series of sensitometric exposure steps. Development was carried out in a special hydroquinone developer which, at maximum gamma, produced pseudomorphic grains, i.e., developed grains having the same size and shape as the undeveloped grains, indicating a surface development of the affected grains.

By visual microscopic observation of exposed, developed, and unfixed slides of one-grain-layer coatings, several cases were found, in which, out of two or more grains having the same shape and size, some grains developed and others did not. The effect appeared to be the same as the one observed by Toy, with exposures in the visible region of the spectrum.

The silver bromide emulsion had a low sensitivity for visible radiation. When treated first with chromic acid and then with bicarbonate, it showed a definite desensitizing effect on exposure to daylight. For x-ray exposures, the sensitometric results were the same for both emulsions within the limits of experimental error. In other words, the grains of these emulsions on exposure to x-rays behaved as if the sensitivity were equally distributed over their surfaces.

If x-rays consisted of waves with continuous energy distributions through the whole beam of incident radiation, then all sufficiently and equally exposed grains of the same size and shape would be developable. This is not the case. *This fact is experimental evidence that sensitivity differences between grains of equal shape and size were produced entirely by the incident x-ray radiation and not by sensitivity differences among the grains.*

To extend this result to different sizes with different shapes of the grains and to reduce restrictions on the validity of this conclusion to a minimum, it was necessary to determine the probable errors. It was found that the probability of these grains' becoming developable by a certain x-ray exposure is proportional to the projective area of the

[6] A. P. H. Trivelli and L. Silberstein, *Phil. Mag.*, **9**, 787 (1930).

grains within the limits of experimental error, confirming the above conclusion more definitely.[7]

The characteristic curve of x-ray exposures, therefore, need not be the result of a sensitivity distribution among the grains, but of a probability of absorbing one or more quanta by a radiation in which the energy is discretely distributed in quanta according to a probability law.

This conclusion can be extended to Toy's grains, and to all other grains which have been made developable by exposure to daylight. The probability of the grains' becoming developable is then no longer proportional to the size of the grains, but to a small measurable fraction of its projective area, ϵa. These grains are not blank targets for the photons as in the x-ray experiments mentioned. Several cases have been described in this paper in which ϵ changes with chemical sensitizing but the quantum number of the emulsion remains unchanged. Investigations of one-grain-layer coatings have repeatedly shown that the value of ϵ diminishes with decreasing grain size of the emulsion. In regular emulsion coatings, we are dealing with a constant, ϵ, for the average grain size of the emulsion. We really measure then $\epsilon\bar{a}$ instead of ϵ. From an analytical point of view we are never dealing with the sensitivity of a single grain in an emulsion, but with an assemblage of a great number of different intrinsic sensitivities among its grains.

It is quite possible and it is even quite probable that grains with the same size and shape have different intrinsic sensitivities. However, we do not know what the probability distribution among these grains is, because we cannot measure ϵ of each grain separately. We can only determine the average value of ϵ of these grains.

Let us suppose that each grain of a certain emulsion becomes developable by the absorption of one effective quantum. This means, according to the quantum theory of exposure, that not every absorbed quantum makes a grain developable. It depends entirely upon the probability of that quantum's being absorbed at a restricted surface, ϵa, of the grain. This determines the sensitivity of a grain. In other words, the sensitivity of a grain depends as much upon its composition as upon the structure of the incident radiation.

It can be concluded, therefore, that *the sensitivity of a grain is interlocked with the discrete structure of the incident radiation.*

SENSITIVITY AND GRAIN-CLUMPING.

All scientific determinations of sensitivity are derived from characteristic curves which vary with the wavelength and the intensity of exposure and with the development conditions. Every change gives another sensitivity value. We have to free ourselves entirely, there-

[7] It should be noted that the latent x-ray image is distributed through the whole grain, and that, for developers with silver halide solvents, the sensitivity of the grain is proportional to its volume and not to its projective area.

fore, from the idea that the sensitivity of a photographic emulsion layer is intrinsically a constant. It is only a constant for all densities of each simple characteristic curve separately. This curve conceals the existence of variables which are not necessarily errors, but which may be essential factors related to the sensitivity of the photographic emulsion. One such factor is the clumping of the grains in an emulsion.

The fact [8] that in an exposed and developed emulsion layer the density is proportional to the number of grains developed eliminates any appreciable effect of grain-clumping on the density, D. If, therefore, k is the number of developed grains out of N exposed grains, then

$$\frac{k}{N} = \frac{D}{D_{\max}}. \tag{6}$$

Svedberg [9] described experiments which show that grain-developability is not transferred from one grain to contiguous ones. With a ferrous-oxalate developer, the number of grains in direct contact with one or more grains was counted; 36.4 per cent. were found to be developed, as compared with 36.5 per cent. of isolated grains. Thus, the percentage of developable grains is not greater when the grains are closely packed together. These results offer convincing evidence for the conclusion that the grain is the unit in photographic reaction, and that developability is not transferred from one grain to another. This evidence confirms the conclusions of Sheppard and Mees[10] and of Slade and Higson.[11] However, these conclusions are in contradiction to the results obtained with an elon-hydroquinone developer by Righter, Sheppard, and the author,[12] who were able not only to measure the frequency of these grain clumps according to their size, but also to show that their sensitivities increased with their size. A tentative explanation of the occurrence of clumps in photographic emulsions as units of photographic reaction was offered by the author.[13] Recent investigations of Stauffer, Smith, and the author [14] have shown that, in certain developers, clumps can form that show contagious action during reduction on neighboring grains, which otherwise would not be reduced by development. Ferrous oxalate does not produce such an action, and this explains satisfactorily why Svedberg observed no clump formation with ferrous-oxalate developer and other investigators found decided clump formation with elon-hydroquinone developer.

[8] A. P. H. Trivelli, to be published in J. FRANKLIN INST., **241**, 1 (1946).

[9] T. Svedberg, *Phot. J.*, **42**, 183 (1922).

[10] S. E. Sheppard and C. E. K. Mees, "Investigations on the Theory of the Photographic Process," Longmans, Green and Co., London, 1907.

[11] R. E. Slade and G. I. Higson, *Proc. Roy. Soc.*, **98A**, 155 (1920).

[12] F. L. Righter, S. E. Sheppard, and A. P. H. Trivelli, *Phot. J.*, **62**, 407 (1922).

[13] A. P. H. Trivelli, *Brit. J. Phot.*, **69**, 687 (1922).

[14] R. E. Stauffer, W. F. Smith, and A. P. H. Trivelli, J. FRANKLIN INST., **238**, 291 (1944).

THE PHOTOMETRIC EQUIVALENT.

Whereas grain-clumping on development of exposed grains is an intrinsic factor of sensitivity, the effect of the photometric equivalent is something quite different.

A nonconverted sensitized silver bromoiodide emulsion, with gelatin containing 2.56 moles per cent. of silver iodide, was coated on a film base and the characteristic curve determined sensitometrically for the exposure to a wavelength of $\lambda = 426$ mμ developed for 12 minutes in DK-50 developer at 20° C. The fog-corrected $D/\log I \cdot t$ curve is indicated by Curve A in Fig. 3. An analysis of the shape of the charac-

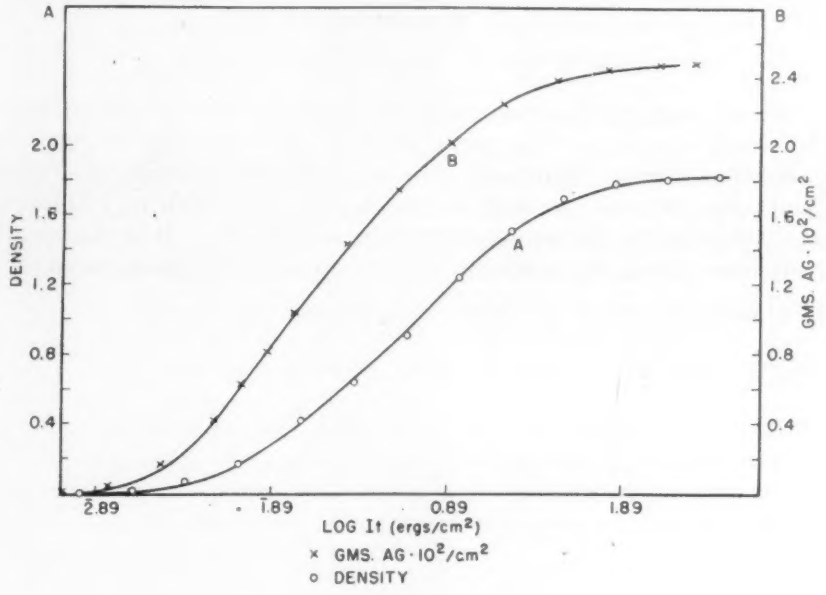

FIG. 3.

teristic curve shows it to be a complex of two two-quantic curves with the equation:

$$D(y) = 0.67F(y) + 1.16F'\left(\frac{y}{m}\right), \qquad (7)$$

in which

$$m = 9.12;$$

and

$$\epsilon_1 = 9.29 \times 10^{-4}, \qquad \epsilon_2 = 1.019 \times 10^{-4}.$$

The solid curve in the figure is the characteristic curve for observed densities and that indicated by open circles is the curve for the calculated densities, showing a good agreement between observed and calculated data.

The silver equivalents of the different densities of this curve were determined by B. Hutchins, of these Laboratories. Instead of plotting the densities against the logarithmic exposure axis, the corresponding amounts of silver were plotted against $\log I \cdot t$. This gives the silver characteristic curve, B. An analysis of its shape shows it to be again a complex two-two quanta curve (indicated by crosses in the figure) with the equation:

$$D(y) = 1.62F(y) + 0.86F'\left(\frac{y}{m}\right), \tag{8}$$

in which

$$m = 11.24,$$

$$\epsilon_1 = 12.81 \times 10^{-4} \quad \text{and} \quad \epsilon_2 = 1.14 \times 10^{-4}.$$

For the meaning of these symbols, the reader is referred to Silberstein and Trivelli's paper.[15] The curve for silver does not differ in shape from the density curve. However, the intrinsic sensitivities of its components are different, so that we are dealing here with real differences in the results of the determination of the sensitivity. It is obvious that the intrinsic sensitivity can only be derived from the silver curve, B.

[15] L. Silberstein and A. P. H. Trivelli, *J. Opt. Soc. Amer.*, **35**, 92 (1945).

TECHNICAL AND TACTICAL FEATURES OF RADAR.

BY

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INTRODUCTION.

The name Radar is derived from the descriptive phrase "*RA*dio *D*etection *A*nd *R*anging." It has been defined as "the art of detecting by means of radio echoes the presence of objects, determining their direction and range, recognizing their character, and employing the data thus obtained in the performance of military action." Now that war has ended its great potentialities will undoubtedly be directed with equal effectiveness to many peacetime tasks.

The superiority of radio energy over heat, light and sound methods for the detection of targets results from its ability to penetrate fog and clouds, and to travel in nearly straight lines at the speed of light over relatively long distances. By virtue of its constant known velocity radio energy has the additional important advantage of providing a basis for direct range measurement from a single point. It can be transmitted at very high power levels and detected at very low power levels.

Radar, more than any single development between the aeroplane and the harnessing of atomic energy, changed the pattern of warfare. It has done it by minimizing the potent weapon of surprise and by greatly increasing the efficiency of many conventional instruments and machines of war.

BASIC APPLICATIONS.

In World War II some of the more important ground radar applications were:

a. Aircraft Warning. In the design of equipment for this purpose emphasis is placed on long ranges rather than extreme azimuth and range accuracies in order to permit ample time to get fighter planes aloft and ground defenses alerted.

b. Gun Laying. Radar for this application embodies a very high degree of accuracy and may be capable of automatically tracking a tar-

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[2] In the preparation of this paper the author has drawn freely from War Department Technical Manual TM-11-467 which was prepared jointly by the War and Navy Departments; and from "Principles of Radar" prepared by the Staff of the M.I.T. Radar School.

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get. The radar, or present position, data are automatically fed into a suitable gun computer which solves the ballistic problem by determining the lead angle, superelevation and fuze setting for each round of gun fire. The usual maximum range of radar systems for this purpose is about 40,000 yards.

c. Searchlight Control. Sets having a range of 20–40 miles and high angular accuracy are used to direct high powered searchlights at ranges much greater than possible by visual perception and with more accuracy.

d. Ground-Controlled Interception. The great air battles over England necessitated the development of this technique of aircraft control. It requires ground-based radar equipment of relatively short range having a high degree of range and angular accuracy and capable of rapid determination of airplane heights. The set is tied into an operational system in such a manner that the ground radar operator can control the flight of a fighter plane by voice radio in the manner required to bring it into a favorable position to attack the detected enemy target.

e. In addition to the above primary functions, ground radar has proved most useful for such special missions as location of ground targets (including mortars and artillery), navigation, road watching, direction of close support bombing, etc.

Air and shipborne radar accomplish parallel functions in their respective spheres of operation. In air warfare, radar played a magnificent role in overcoming two basic limitations to effective offensive operations; namely, bad base weather and bad target weather. Our bombers went out equipped with radar fully capable of detecting such landmarks as cities, mountains, rivers, etc., thereby insuring unerring navigation to the target area. Where bad weather precluded a visual bomb run, they actually lined up on the target and bombed by radar alone. Upon return to base, the planes were safely landed under conditions of low visibility by Ground Control Approach radar.

Likewise, it is now possible for ships to fight through entire engagements in which the enemy may be detected, bombarded and sunk without ever coming into visual range. During such a battle, the ships may remain in battle formation, travelling at high speeds through narrow waters because they continually "see" one another and the shore by radar.

The multiplicity of tactical situations in which radar is useful immediately indicates that it can be no single instrument, but must be tailored to fit each particular application. However, despite wide diversity in form, every radar set embodies a common set of principles basic among which is the use of reflected radio waves or "echoes."

RADAR SYSTEM FUNDAMENTALS.

The method of operation employed in most service radar equipment is the "pulse system" whereby pulses of high power electromagnetic energy of very short duration are transmitted, and the resulting echo pulses reflected from distant targets detected and indicated. The pulse-echo process is repeated at a rate which permits the integration of a number of echoes into a single effect, usually within a cathode ray tube, for appropriate indication.

The basic functional elements of a conventional pulse-echo radar system generally consist of the following essential components:

a. A *timer* which supplies all the synchronizing signals to the circuits and components of the system required to insure that they operate in proper time relationship with each other; and fixes the pulse duration and repetition frequency of the transmitter.

b. A *transmitter* which uses a simple oscillator to generate electromagnetic energy in the form of short powerful pulses. Generally transmitters in the microwave frequency band use magnetrons as oscillators while in the lower radar frequencies vacuum triodes are used.

c. An *antenna system,* directly coupled to both the transmitter and receiver, which takes the radio-frequency energy from the transmitter, radiates it in a suitable directive manner, receives any returning echoes and transmits them back to the receiver.

d. A *receiver* which amplifies the relatively weak returned echoes and reproduces them as video signals suitable for impression on the screen of a cathode ray tube indicator.

e. An *indicator* which produces the visual indication of the echo pulses in the manner required to provide the desired information in each particular radar application.

f. In addition, a *source of power,* usually a motor-generator set, along with *power supplies* for supplying the special a.c. and d.c. voltages required to operate the various components, are necessary to provide an operable radar system.

A simplified functional block diagram of a conventional pulse radar system is shown in Fig. 1. In actual practice a system may contain several functional elements in a single physical component or vice versa. In fact it is common practice to build the circuits comprising the timer right in the components to which they are related.

The antenna system as shown in Fig. 1 includes a component known as the transmit-receive switch or "T-R Box." It is a device which couples the transmitter to the antenna during transmission of the pulse and then connects the receiver during the interval between pulses, thereby enabling the use of a single antenna system for both transmitting and receiving. One commonly used type of T-R Box employs a spark gap with associated resonant systems, which fires during the trans-

mission of a pulse thereby detuning the receiver coupling circuits to prohibit the transmitter power from reaching the receiver.

TECHNICAL CHARACTERISTICS OF MAJOR SYSTEM COMPONENTS.

Timer. The circuits which control and synchronize the operation of various elements of a radar set constitute the timer or control central. In the self-synchronized type the timing function is accomplished within the transmitter circuits. This is generally the simplest method of synchronizing a radar system and is suitable for search type radars where instability of pulse repetition frequency is not a serious factor. Furthermore, simple modulators such as the rotary spark gap can be

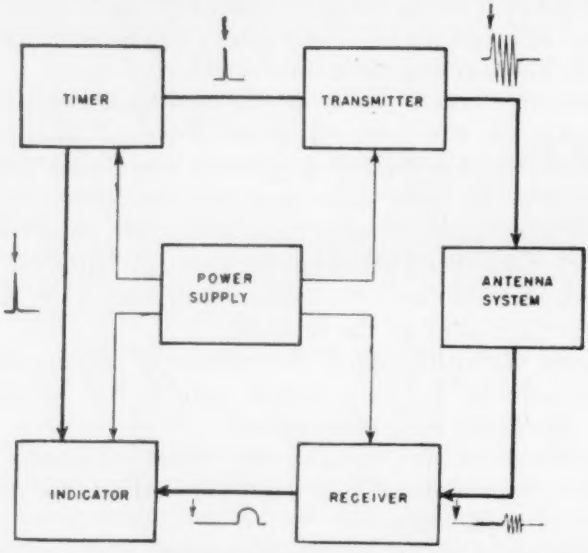


FIG. 1. Functional block diagram of a fundamental radar system showing wave forms from each component.

used with the self-synchronous timers. Timing the operation of all other components from the transmitter prevents errors in range measurements and insures sharper definition of echo signals on the indicator screen. However, in such a system it is sometimes difficult to overcome the appreciable delay which occurs in the beginning of the range sweep in the cathode ray tube.

The other commonly used timer is the externally synchronized type which employs a master oscillator to establish its repetition rate and to supply trigger voltages to all other components of the system. The type of master oscillator employed depends upon the requirements of the system. It may be either a sine wave oscillator, a single swing blocking oscillator, or a multivibrator depending upon the variety of wave shaping circuits desired.

While the functions performed by the timer vary in detail from one radar system to another, the commonly used diagram shown in Fig. 2 is a typical representation of the more common control pulses emanating from the unit. The way in which these timing signals function in a system is illustrated in the conventional time relationship diagram shown in Fig. 3. While this diagram is typical of the externally synchronized system where the transmitter is triggered by a signal originating in the timer, it is equally applicable to the self synchronous system where the time reference pulse is generated in the transmitter circuit. In the latter case the pulse labeled "transmitter trigger" would become

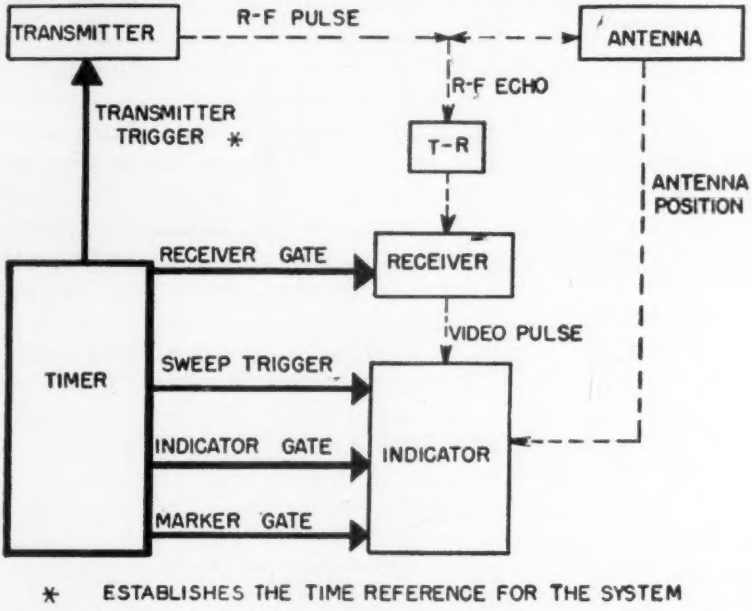


FIG. 2. Diagram showing typical timing pulses produced in a radar timer.

"timer trigger." In either case, however, that pulse constitutes the reference point from which the whole system operation is synchronized.

Another timing signal (Fig. 3③) gates the receiver to make it operative only during the portion of the pulse cycle in which echoes from targets throughout the range of interest are received. While a transmit-receive switch limits the transmitter signal entering the receiver sufficiently to prevent damage it may still be strong enough to drive the grid voltage in the video amplifier stage below the cutoff value thereby causing blocking. When this happens the receiver remains inoperative for a recovery period sufficiently long to prohibit reception of echoes at short ranges. To prevent this condition, the timing signal applies a positive rectangular voltage to the screen and plate of one or more of

the early stages of the intermediate frequency amplifier during the interval beginning just after the end of the transmitted pulse and ending after reception of echoes from the most distant range of interest. In this case, the minimum detectable range of the radar becomes a function of the transmitter pulse duration. Recent improvements in receiver and T-R Box design have shortened recovery time to the extent that a receiver gate is not always necessary in the new sets.

The range sweep (Fig. 3④) in the indicator circuits is also synchronized by a timing signal commonly referred to as the "sweep trigger."

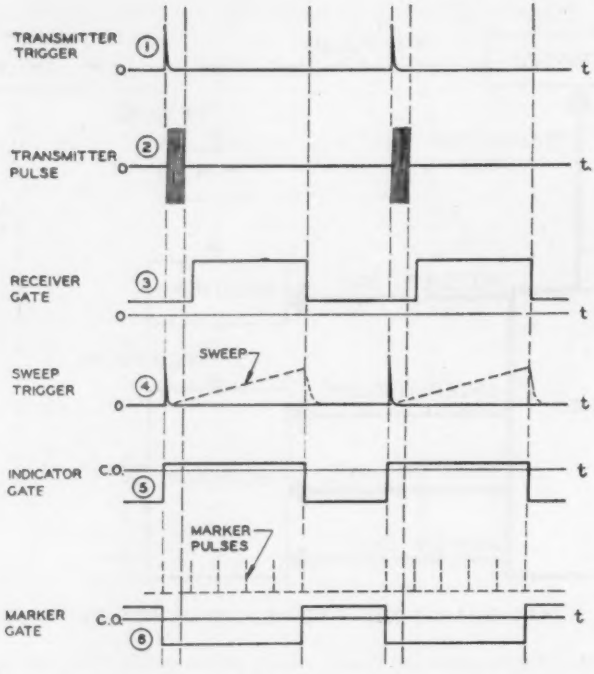


FIG. 3. Diagram showing the time relationship of the timer pulses indicated in Fig. 2.

It is timed so that the actual beginning of the sweep on the cathode-ray tube face exactly coincides with the beginning of the transmitted pulse.

In order to eliminate the appearance of echo signals from targets outside the desired range an indicator gate signal (Fig. 3⑤) is necessary. This is a rectangular voltage applied to the grid of the cathode ray tube reducing its bias enough to permit operation of the tube during the desired portion of the pulse cycle.

Where it is desirable to estimate range directly from the tube face it is often convenient to superimpose signals (Fig. 3⑥) commonly called "marker pulses." The markers are pulses of very short duration which are gated by a rectangular pulse provided by the timer and spaced in

time so that the distance between each marker on the tube face corresponds to a definite range increment. The marker gate limits operation of the marker pulses to the period of the range sweep.

Transmitter. Radar transmitters may be either self-pulsed or externally pulsed. The self-pulsing transmitter combines the function of transmitting and timing into a single unit. Its carrier frequency is determined by the inductance-capacitance constants of the tank circuit and its pulsing frequency by the resistance-capacitance constants of the grid circuit. The grid capacitor determines the transmitted pulse duration and the grid-leak resistor its repetition frequency. The timing pulse used to synchronize other components of the radar system is developed across a resistor in the cathode circuit of the blacking oscillator.

American radar systems usually employ the externally pulsed type of transmitter. In this system the function of the radio-frequency oscillator is simply to generate powerful pulses of R-F energy at regular intervals. Since the actual transmitting time is a very small part of the complete pulse cycle, the oscillator can be heavily driven during transmission to gain high output power. A properly timed high amplitude rectangular pulse is necessary to excite this type of transmitter. Generally, a driver and a modulator are required. The driver is triggered by a signal from the timer. It forms and supplies an accurately timed rectangular pulse to a suitable modulator where it is greatly amplified and fed to the transmitter in the form of a timed, high amplitude, rectangular pulse of definite duration.

The carrier frequency at which the system is to operate generally controls the type of radio-frequency oscillator to be used; and the frequency depends on its tactical use, desired antenna directivity, and other factors. For frequencies up to about 600 megacycles the simple triode oscillator is generally used. All of the early radar sets used a triode transmitter. At frequencies above 400 megacycles interelectrode capacitances, increased electron transit time, lead inductances and stray capacitances in the conventional triode become troublesome, and above 600 megacycles this type of oscillator becomes too inefficient for practical application. Above 600 megacycle frequency the magnetron is by far the most efficient radio-frequency generator presently known. It is well adapted to radar use because it is capable of delivering the extremely high peak power output necessary to obtain desired ranges. The range of frequencies over which magnetrons are practical is generally known as the microwave region.

Electrically the magnetron can be considered to be a special diode in which a magnetic field is set up perpendicular to the electric field existing between the cathode and the plate. The magnetic field which may be supplied by either an electromagnet or a permanent magnet, is the force which, when applied at proper value in relation to the applied

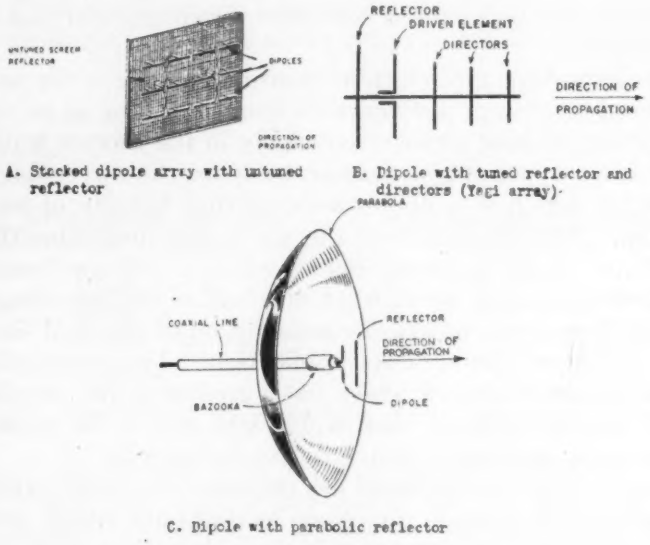
voltage, causes the electron cloud to form the necessary orbits for oscillation. The most common method of applying plate voltage is to ground the case, insulate the cathode and apply a negative voltage in the form of a rectangular pulse directly to the cathode. The radio frequency is taken from the magnetron by coupling the transmission line to the inside field with a small loop. While a triode oscillator may be either self or externally pulsed, magnetrons are always externally pulsed. Furthermore the plate voltage required for operation of a magnetron is high and must be fairly rectangular in shape to prevent unwanted modes of oscillation.

Antenna Systems. The approximate size, shape and electrical characteristics of radar antenna systems are determined by the carrier frequency and the tactical application of the equipment. However, in all cases the antenna system is considered to include the feed line from the transmitter to the antenna, the antenna array, the feed line from the antenna to the receiver, and the T-R Box. Its common function is to receive electromagnetic energy from the transmitter, radiate it in a directive pattern, receive the target echo signal and send it back to the receiver. To obtain peak performance from a radar set its antenna system must be efficient, which means that the energy produced by the transmitter must be radiated and the received energy returned to the receiver with minimum losses. Where a single antenna is used for both transmitting and receiving this can be accomplished best by accurately matching the antenna to the characteristic impedance of the R-F lines. During transmission of the pulse, the transmitter should be properly matched to the transmission line and the receiver mismatched so as to present a high impedance to the line. A reverse condition should exist during reception of the echo. This switching problem, which is done by the T-R Box, previously mentioned, requires an electronic device which can accomplish what amounts to a double-pole double-throw switch for connecting the antenna alternately to the transmitter and the receiver at rates sometimes faster than one microsecond. Such devices as spark gaps, R-F amplifiers, resonant transformers and klystrons with appropriate circuits are commonly used for T-R switches.

A radar antenna system may employ any one of several types of radiators depending upon the frequency of operation and general requirements of the system. At frequencies below 600 megacycles either a stacked-dipole array with untuned reflector (Fig. 4A) or a dipole with tuned reflector and directors (Fig. 4B) is generally used. In the former case increased directivity is obtained by increasing the number of dipoles in each dimension of the array while in the latter case the tuned reflector and directors are parasitically excited by a single driven dipole and reradiate the energy with a phase relationship to the driven element which reinforces its field in a forward direction. At frequencies of 600 megacycles or above the antenna usually consists of a dipole(s) located

at the focal point of a parabola with a parasitic reflector located about one-quarter wavelength in front of the dipole (Fig. 4 C). The parasitic reflector causes the radiated energy to be reflected backward to the parabola where it is reflected forward in a manner closely analogous to the reflection of light by a parabolic mirror. The greater the ratio of diameter of the parabola to the operating wavelength the more directional the beam pattern becomes.

Several types of antenna feed systems are in common usage for radar sets. The simplest is the open two-wire system which can be constructed with characteristic impedances varying from 150 to 1,000 ohms. Either solid wire or tubing accurately spaced by ceramic or



A. Stacked dipole array with untuned reflector

B. Dipole with tuned reflector and directors (Yagi array).

C. Dipole with parabolic reflector

FIG. 4. Three principal types of radiators employed in radar antenna systems.

stub support insulators may be used. The stub support is generally most satisfactory. It consists of a quarter-wave transmission line short circuited at one end causing the other end, which is attached to the line, to present a high impedance to the line load. The quarter-wave stub supports can be mounted directly to the metal antenna tower. The two-wire line is matched to the antenna and transmitter by matching stubs which can be placed any place along the line. While an open wire system is simple it has the disadvantage of direct radiation from the lines which results in considerable losses. The higher the frequency the greater are the losses, hence, use of the open line is generally limited to radars operating at frequencies below 400 megacycles.

Coaxial transmission lines have the advantage over open lines of being completely shielded, thereby eliminating radiation losses. The

energy is carried entirely within the outer conductor, hence, its outer surface is at ground potential and may be easily mounted. Such lines are used in most radar equipments which operate at frequencies from about 400 to 3,000 megacycles. In a rigid coaxial line the inner conductor is centered in respect to the outer conductor by ceramic or polystyrene spacers. For the higher frequencies it is desirable to mount the inner conductor by means of quarter wave short-circuited stubs to minimize losses. In a flexible coaxial line stranded conductors supported by either continuous flexible solid insulation or by closely spaced beads are used. While this type is easy to install it inherently has greater losses than the rigid line.

Coaxial lines are unbalanced with respect to ground and require a special transformer or balanced converter for connection to a balanced line or antenna.

Another important type of radar transmission line is the waveguide. It can be used advantageously on wavelengths as long as 20 cm. (1,500 megacycles) and is used almost exclusively in the shorter wavelengths. Unlike the other types of transmission systems, the waveguide has only one conductor which is a hollow tube or pipe usually of rectangular cross section. The dimensions of the waveguide determine the critical wavelength, or cutoff frequency below[4] which it will not transmit. Its longest dimension must be at least one-half of the wavelength to be transmitted, hence, the practical consideration of physical size governs the lower frequency limit of its application. The waveguide is free from radiation and dielectric losses, has a greater power carrying capacity than a coaxial cable of comparable size and is the most efficient known transmission system for microwave frequencies.

Receivers. When transmitted electromagnetic energy strikes a target it is reflected in random directions so that only a very small signal returns to the set. It may sometimes be less than 2×10^{-14} watts which corresponds in amplitude to one microvolt impedance across a 50 ohm resistance. In order to obtain the operating stability and extreme sensitivity required to detect and amplify such weak signals, radar receivers must be skillfully designed. The superheterodyne type receiver provides higher gain with fewer tubes than do other types and is used almost exclusively. A simple block diagram showing the basic components of such a receiver are shown in Fig. 5. The weak echo signals are received in the R-F amplifier and fed to a mixer where its frequency is reduced by beating it with a lower frequency signal generated in a local oscillator. This mixing produces an output voltage at a frequency equal to the difference of the two applied signals. The new intermediate frequency signal is amplified by stages to obtain higher

[4] See Slater's "Microwave Transmission," page 137, formula (15,18): "The longest wave that can be transmitted in a rectangular pipe has a half wavelength equal to the greater of the two dimensions of the pipe."

overall gain, detected and further amplified in the video stage from which it is fed to a suitable indicator, usually through a cathode-follower stage.

The primary consideration in receiver design is to keep the internal noise level low in order to maintain the highest possible signal-to-noise ratio. Since echo signal strength decreases with increasing target range, lowering the noise level of a receiver enables detection of weaker signals. However, the thermal agitation of electrons within the first circuit determines the minimum noise level attainable in receiver design.

Indicators. The radar indicator accepts the video signals from the receiver and produces them visually in a manner to provide the desired information. The cathode ray oscilloscope is universally used for this purpose. It is ideally suited because it not only provides indication of changes in a single quantity such as voltage, but also permits quantita-

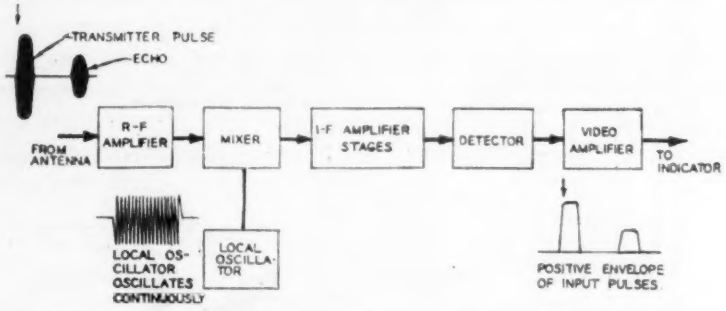


FIG. 5. Block diagram of a conventional superheterodyne radar receiver.

tive comparisons of two or more synchronized variables. Basically, the radar indicator is only a refinement of the standard low frequency test oscilloscope. The focusing, intensity, and positioning controls are similar. The sweep frequency is synchronized with the pulse repetition rate of the radar system and its duration is set to permit desired range coverage.

Two types of cathode ray tubes having screen diameters varying from two to twelve inches, are commonly used in radar indicators. One type is the *electrostatic* cathode ray tube in which the electron beam is made to follow the desired pattern by controlled differences in potential between pairs of deflecting plates. This type is generally used in the simpler types of data presentation such as is required for early warning or long range radar systems. The other type is the *electromagnetic* tube where a magnetic instead of an electric field is used for both focusing and deflection of the electron beam. The magnetic deflecting coils are mounted outside the tube. The electromagnetic tube is generally used in the more highly refined types of data presentation required in high precision radar sets.

In addition to the cathode ray tubes, radar indicators include the timing circuits required to provide range sweeps, intensifying and blanking signals, and special power supplies to provide the high and low voltages for operating the indicator tubes. Azimuth and elevation sweep control mechanisms required to connect the antenna system to the respective sweeps of the cathode ray tube are also included in the indicator unit.

Many types of data presentation are required for the various tactical radar applications. Four of the more important types are illustrated in Fig. 6. The simplest of these is the *A-scan* which employs an electro-

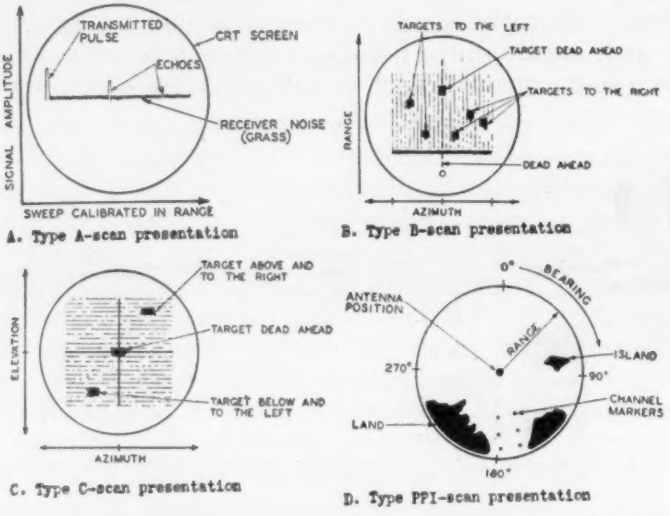


FIG. 6. Four of the principal methods of target indication on cathode ray tube screens used in conventional radar sets.

static cathode ray tube. A linear time sweep synchronized with the transmitter pulse is applied to the horizontal deflecting plates and travels across the tube face as each pulse is transmitted. The video output of the receiver is applied to the vertical deflecting plates causing a vertical deflection (or pip) at the instant a signal is received. By calibrating the time base in terms of distance, range can be read directly. Since the height of the pip corresponds to signal strength, azimuth can be determined by rotating the directional antenna to the position of maximum signal strength and reading its bearing from an appropriate indicator dial.

In the *B-scan*, the azimuth is plotted as the abscissa and range as the ordinate directly on the oscilloscope tube screen. To obtain this presentation the time sweep signal is applied to the vertical deflection coils of an electromagnetic cathode ray tube and a positioning current determined by the position of the antenna is applied to the horizontal

coils. Sectors up to 180 degrees can be covered with the *B-scan*. The oscilloscope is intensity modulated by the receiver output signal which causes the target to appear as a spot on the tube screen.

The *C-scan* is similar to the *B-scan* except that elevation instead of range is plotted against azimuth. Its primary application is in airborne radar as a remote indicator for use of combat pilots in effecting an interception.

The *PPI-scan*, meaning "plan position indication," is widely used in all radar not requiring elevation data. It presents, in polar coordinates, a map of the entire area around the antenna location. The time (range) sweep position is synchronized with the antenna position throughout 360 degrees rotation and sweeps from the center radially outward. The tube is normally biased so that the scan is at the threshold of visibility enabling display of the returned echo signal as a spot by intensification. Hence, the distance of the spot from the center of the tube screen provides a measure of the target range and the polar angle of the radial line through the spot represents its azimuth. An outline map of the area covered by the radar is often superimposed directly on the tube face together with the appropriate Army grid coordinate system to further facilitate accurate reading and interpretation of the radar data.

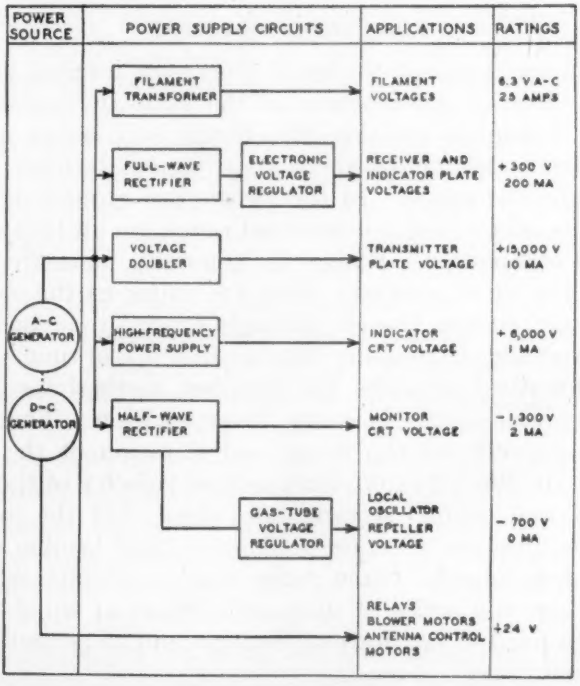


FIG. 7. Block diagram showing power requirements for a typical microwave radar set.

The screen materials used in cathode ray tubes are called phosphors. The composition of the phosphors determines the color of light emitted when bombarded with a stream of electrons which usually have an energy of about 4,000 electron volts, and also determines the persistence of the screen.

The long signal persistence required in most radar applications has been obtained by using what is known as a cascade or "memory" screen. It is composed of two active layers of phosphors; a blue layer closest to the electron gun and a yellow layer between the blue one and the face of the tube. When the electron beam, representing the received target signal, strikes the first layer a brilliant blue flash is emitted which excites the yellow layer causing it to emit a glow for a considerable time, thereby achieving long persistence. The actual luminous output of any tube screen depends on the accelerating voltage applied to the tube plates and the length of time a particular area of the screen is bombarded with electrons.

Power Supplies. The total power requirements of conventional radar systems vary greatly in magnitude from set to set but all equipments require numerous special supplies which are generally built into the respective components. The diagram shown in Fig. 7 illustrates the diversified power requirements of a typical microwave radar equipment.

RADAR SYSTEM OPERATION.

Radar sets are designed to detect objects of interest and to locate them with accuracies consistent with the tactical requirement of the application. Complete location of a target such as an aeroplane requires the determination of three coordinates; bearing or azimuth, elevation angle and range. In the location of ground or water-borne targets, the coordinates of azimuth and range are all that are required.

Range Determination. Range is generally measured as "slant range"; i.e., the direct distance from the radar to the target. Since radio frequency energy travels through space at a constant known velocity, it is possible to measure distance in terms of time. The *A-scan* previously described provides the simplest method for utilizing the time-distance relationship in range determination. The accuracy of this method depends on the shape and duration of the transmitted pulse, and to the linearity and constancy of velocity of the sweep spot. Short and/or well defined rectangular pulses yield the most accurate range data because the accurate position of their leading edges can be most easily determined. Often range marker circuits, which produce on the tube screen a series of spots or markers at equal increment of range, are provided to facilitate calibration and to permit easy reading of range values.

The range accuracy required of a radar set varies with its tactical

application. In long range warning equipment, range errors of one or more miles can be tolerated in order to achieve simplicity of design and operation while in gun laying sets errors must be held to the order of plus or minus ten or fifteen yards in order to attain a high probability of the shell either hitting the target or exploding in burst-range of it.

Many refinements for obtaining very high range accuracies are possible both in circuit design and in methods of presentation. When necessary the length of sweep may be increased by making it appear in a series of horizontal lines on the screen, by using a larger cathode ray tube, by using two tubes—one for rough and one for fine indication, or by using a circular baseline whereby the echo signals are impressed as radial deflections.

Azimuth Determination. Direction of a target is generally measured as an angular quantity. Land based radars are oriented in respect to true north and the bearing of the target determined from that reference. Airborne and shipborne systems are generally oriented in respect to the direction of travel, although they may be automatically oriented with respect to true north by a servo connected to the gyro or magnetic compass.

The accuracy with which the angular position of a target can be determined is a function of the directional characteristics of the antenna system. In highly directional antennas the angle about the principal axis of the radiation pattern within which the radiated energy is of approximately uniform intensity is small, hence the antenna can be oriented for maximum echo signal strength with a high degree of accuracy.

The extent of beam directivity necessary in each type of radar equipment is determined by the azimuth accuracy requirements of its particular application. In long range search systems beam widths up to 15 or 20 degrees are permissible. In accurate tracking radars, such as gun-laying equipment, extreme angular accuracies are necessary.

Antenna directivity is generally increased by either increasing the physical size of the reflector or decreasing the wavelength of the radio frequency energy. Sometimes, however, it becomes inconvenient to reduce the beam width sufficiently to provide the angular accuracy necessary. In such cases two slightly overlapping beams (lobes) are radiated and the echo from each received alternately. Usually the two beams are formed by causing a single antenna beam to oscillate over the desired angle by either electrical or mechanical means. This system is known as *lobe switching*. Figure 8 illustrates the general principle of direction finding by this method. The antenna is rotated until the returned signals from both lobes are of equal intensity. At that position, the target is exactly on the median line of the two lobes, permitting accurate determination of its angular position. Some form of lobe switching is generally used in the lower frequency equipments

when it is desired to obtain better azimuth accuracies without increasing the antenna size.

In microwave high precision gunlaying sets a system known as "*conical scanning*" is used. The characteristics of an antenna pattern conically scanned are illustrated in Fig. 9. An off-center lobe is produced either electrically or mechanically and rotated about the axis of a parabolic reflector thus describing a cone in space. This principle allows accurate determination of both azimuth and elevation simultaneously by rotating the parabolic reflector in both horizontal and vertical planes until the target echo has the same amplitude for all positions of the lobe.

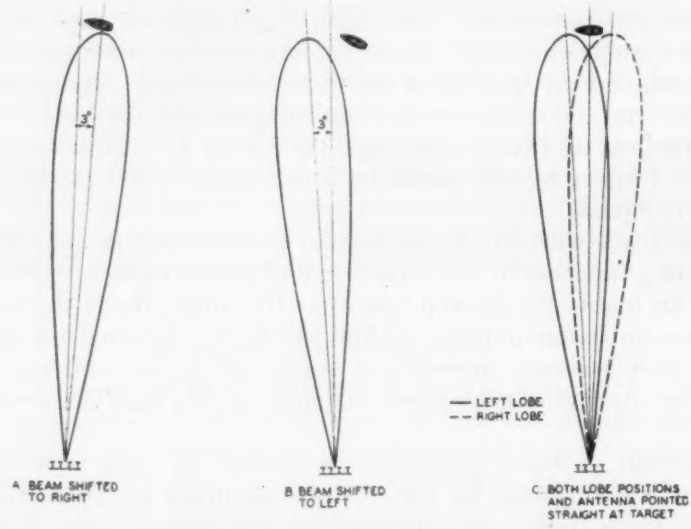

A BEAM SHIFTED TO RIGHT
B BEAM SHIFTED TO LEFT
C BOTH LOBE POSITIONS AND ANTENNA POINTED STRAIGHT AT TARGET
LEFT LOBE
RIGHT LOBE

FIG. 8. Sketch illustrating the principle of lobe switching for azimuth determination.

Elevation Determination. This dimension, along with range and azimuth, makes possible the complete location of a target in space. The simplest method of elevation measurement makes use of either a conical scan or an antenna system with an extremely narrow beam in the vertical plane, either of which permits measurement of the elevation angle direct. Continuous elevation data can be obtained by using a simple range-height converter which employs the sine function to convert slant range and elevation angle data to altitude values.

Operational Refinements. The radar art has reached such a high state of development that it is now possible to build equipment which will perform with any accuracy desirable for its use with appropriate existing ordnance weapons. In addition to automatically and continuously transmitting accurate present position data to gun computers, searchlights, plotting rooms, etc., the human element has been still

further minimized by incorporating *automatic* and/or *aided tracking* in the higher precision radar sets. The automatic tracking refinement is accomplished by making use of a signal from the receiver (error voltage) which is always proportional to the error in instantaneous direction of the antenna. This signal is applied to a suitable electro or hydro-mechanical system, commonly called a servo system, which automatically restores the antenna to the correct position. Thus, some radars are capable of following a target automatically in range, azimuth and elevation. Aided tracking is accomplished by setting a definite rate of change of position into the servo system which then changes the antenna position accordingly. Each change in the speed and/or course of the target requires a new adjustment of rate of change in the system.

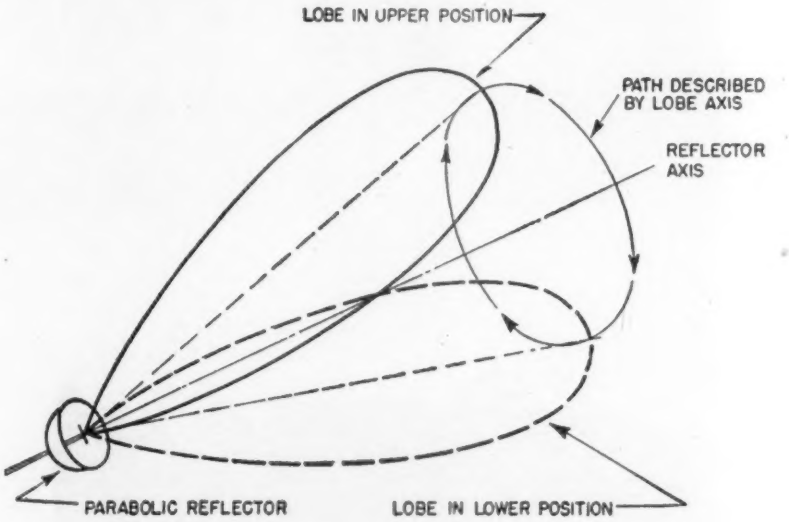


FIG. 9. Sketch illustrating principle of conical scanning.

Recognition of Targets. Perhaps the least developed aspect of radar is that phase concerning the recognition of targets. To a radar all objects of similar reflecting qualities are identical. Experienced and well trained radar operators are usually able to determine the nature of a target in a general way from such factors as its speed, strength of echo, etc., but no definite identification is possible. A special type of apparatus, known as IFF (identification of friend or foe), has been developed to work with radar equipment to distinguish between friendly and enemy targets. It uses the radar pulse technique but comprises special equipment for sending the challenging signal, and other special equipment mounted in the friendly target to receive the signal and return an identifying code signal back to the challenging station. Radar beacons capable of receiving a pulsed signal and transmitting a

coded signal are also used for identification, particularly of friendly ground targets and navigation routes. The radar is able to determine both range and direction of such recognition signals.

SYSTEM DESIGN FOR SPECIFIC APPLICATIONS.

It has been shown that certain operating principles are common to all radar systems. Any reasonable performance characteristics can be obtained at the present state of the radar art; however, extreme refine-

FIG. 10. Radio Set SCR-271-D.

ment usually requires large, complicated and heavy weight components. Then, for each tactical application, design of a system becomes a problem of technical compromise, i.e., incorporating necessary precision in certain respects at the expense of refinement in other less essential features; or compromising overall accuracy and/or range to gain simplicity and lightweight.

Each tactical requirement presents certain limiting factors which must be met in the design of radar equipment. Among the more important of these factors are: (1) the maximum permissible size and

weight of each component and of the total system; (2) the range and angular coverage necessary; (3) the minimum acceptable accuracies in range and angular measurements, and (4) the constructional features required for the particular type of installation. When these parameters are known, it is possible to select certain radar system constants which will provide the best possible performance characteristics for that particular application.

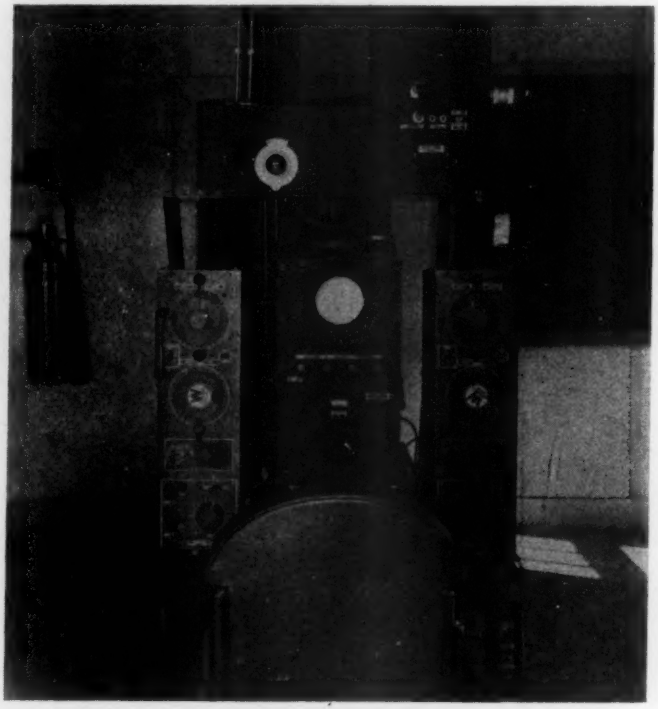


FIG. 11. Radio Set SCR-271-D.
Operating equipment RC-205. Oscilloscope BC-403-D.
Interference reducer BC-736-A. Receiver BC-404-C.

In the design of the SCR-271-D shown in Fig. 10 the primary consideration was long range coverage against aircraft. Extreme range and azimuth accuracy was not imperative; neither was target elevation. Accordingly, a long wavelength of approximately 300 cm. was chosen as the operating frequency; and a peak power output of 100 kw. transmitted in pulses of 15–30 microseconds at a repetition rate of 621 pulses per second was used to obtain ranges from 5 to 150 miles at an accuracy of ± 4 miles. The antenna array, 8 dipoles high by 4 dipoles wide, permits an azimuth accuracy of ± 4 degrees.

A simple indicator (shown in Fig. 11) consisting of a conventional

A-scan oscilloscope for range measurement and an electro-mechanical antenna control system with dials for direct azimuth reading is used on the SCR-271-D.

This set was put into service late in 1941 and served effectively throughout World War II for fixed station early warning against aircraft.

Despite the fact that this equipment was available (as the SCR-270) in mobile form, the Army urgently needed a lightweight transportable early warning set for use in forward areas of military operation which

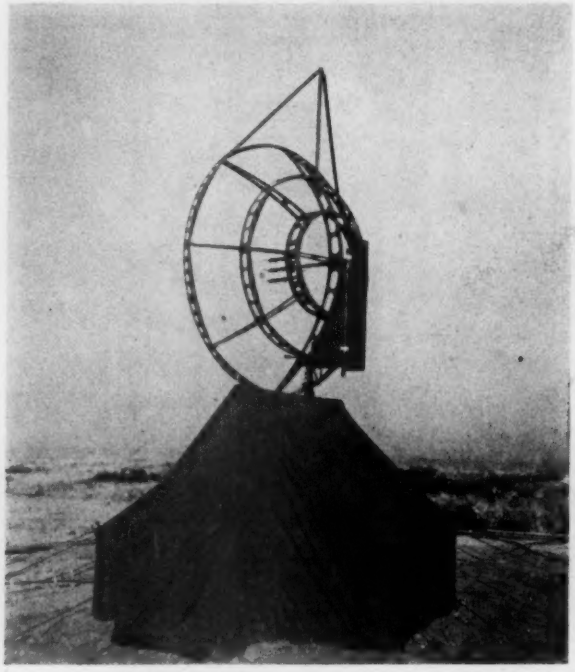


FIG. 12. Radio Set AN/TPS-3. Rear view. Showing entire set. Prepared for early warning.

would have an effective range of about 100 miles. Radio Set AN/TPS-3 shown in Fig. 12 is one of the radar sets designed for that requirement.

To achieve the lightweight, long range, high degree of transportability and accuracy desired, an operating wavelength of 50 cm. was used. This higher frequency permitted the use of much smaller components and a 10-foot parabolic reflector with a single dipole (or three displaced dipoles) with lobe switching. A newly developed triode tube provides a transmitter power output of 250 kw. which is pulsed at 200 pulses per second with a pulse duration of about 1.5 microseconds. A bomber flying at 10,000 feet can be detected at ranges from 5 to 100 miles and

located with a range accuracy of ± two miles and an azimuth accuracy of ± two degrees.

The complete operating console of Radio Set AN/TPS-3 is shown in Fig. 13. It includes a conventional *A-scan* oscilloscope for range measurement and a PPI scan oscilloscope for general surveillance and azimuth determination.

The set breaks down into twelve packages having a gross weight of

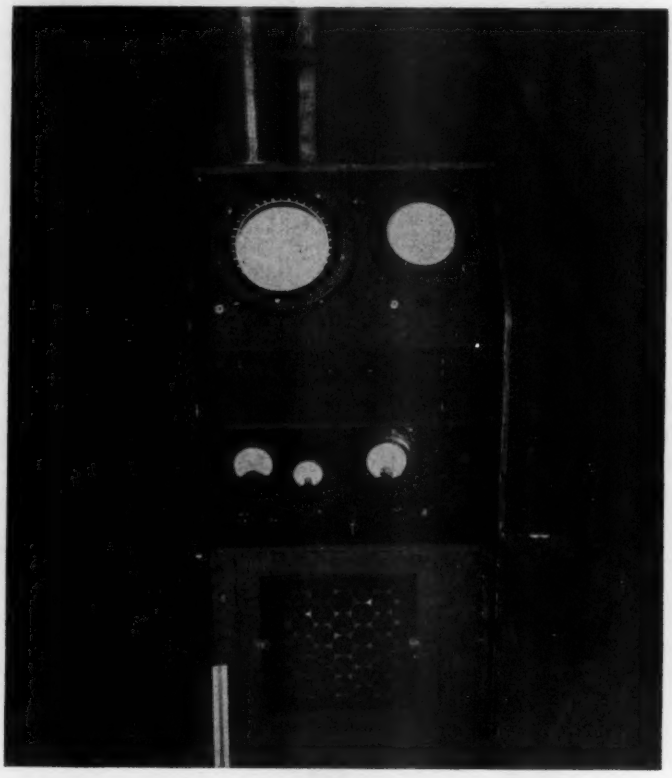


FIG. 13. Radio Set AN/TPS-3. Complete console.

1,340 pounds when packed for air transport. It can be set up and placed in operation in about 30 minutes.

No discussion of radar would be complete without mention of the SCR-268, the Army's first searchlight and fire control radar. While this equipment is extremely heavy and bulky and does not have sufficient accuracy for satisfactory gunlaying operations, it accomplished valuable service until more highly refined sets became available. Through its use—and shortcomings—the patterns for new sets were made.

One of these is Radar Set AN/TPL-1 shown in Fig. 14. This set

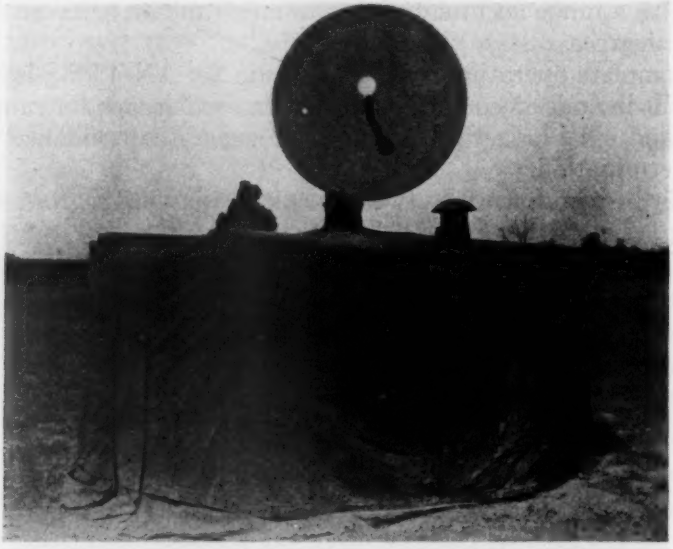


FIG. 14. Radar Set AN/TPL-1. In operating position with canvas shelter installed.

was designed to meet the tactical requirements for a transportable searchlight control set. It covers a range of 500 to 60,000 yards and has a range accuracy of ± 200 yards. An aircraft can be tracked in both azimuth and elevation with an accuracy greater than ± ½ degree.

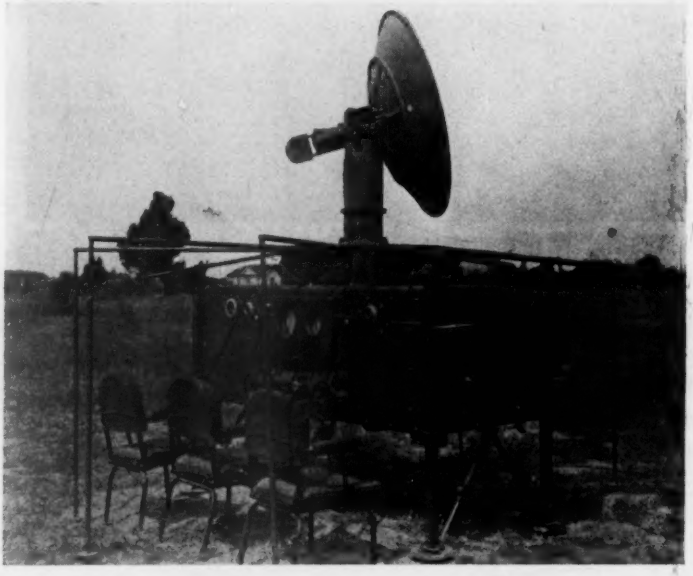


FIG. 15. Radar Set AN/TPL-1. In operating position with canvas shelter removed.

To achieve that performance and to stay within the size and weight requirements, the set was designed to operate on 10 cm. wavelength and to employ a spinning dipole in a four-foot paraboloid to produce a conical 10 degree radiation pattern. A magnetron is used to produce a peak power output of 125 kw. which is radiated in one microsecond pulses at a rate of 400 pulses per second. Aided range tracking is also provided.

The indicator of the AN/TPL-1 (see Fig. 15) uses a PPI oscilloscope for general surveillance, a 5-inch *A-scan* 'scope for range tracking and two 2-inch A'scopes with pip matching for azimuth and elevation tracking, respectively. A specially designed chassis and wheels mount directly on the console to facilitate loading on a trailer for transport. Early in the war tactical requirements for a compact, highly mobile, and accurate fire control radar for antiaircraft artillery resulted in the development of several new sets. One of the most important of these is Radio Set SCR-584 shown in Fig. 16. The SCR-584 is a very highly refined radar, incorporating automatic target following in azimuth and elevation and aided tracking in range. Tracking accuracies of the order of ± 15 yards in range and ± 0.1 degree in azimuth and elevation are possible with this set. It is designed to operate with certain standard antiaircraft gun computers. In addition to its tracking capabilities

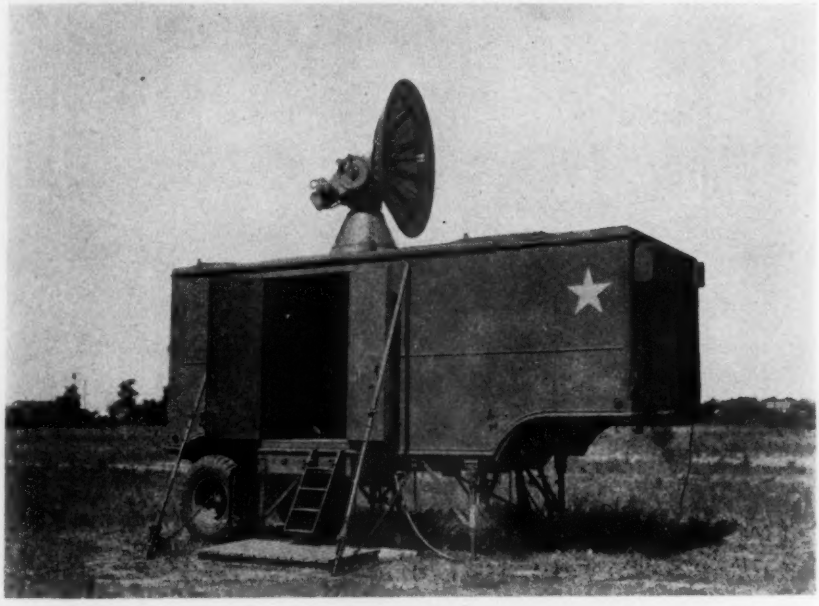


FIG. 16. Radio Set SCR-584. In operation on trailer K-78.

over ranges from 500 to 32,000 yards, the SCR-584 can be used for general surveillance to a range of 70,000 yards.

The indicator and control panel of the SCR-584 is shown in Fig. 17. The indicator contains a PPI oscilloscope for surveillance and two range scopes—for coarse and fine indication, respectively. Azimuth and elevation data are directly indicated by dials. All data is electrically transmitted to a computer by one and 16 speed selsyns.

To achieve this performance the set was designed to operate at 10 cm. wavelength; to use a magnetron oscillator having a peak power output of 300 kw. and a rotating dipole in a 6-foot paraboloid reflector with

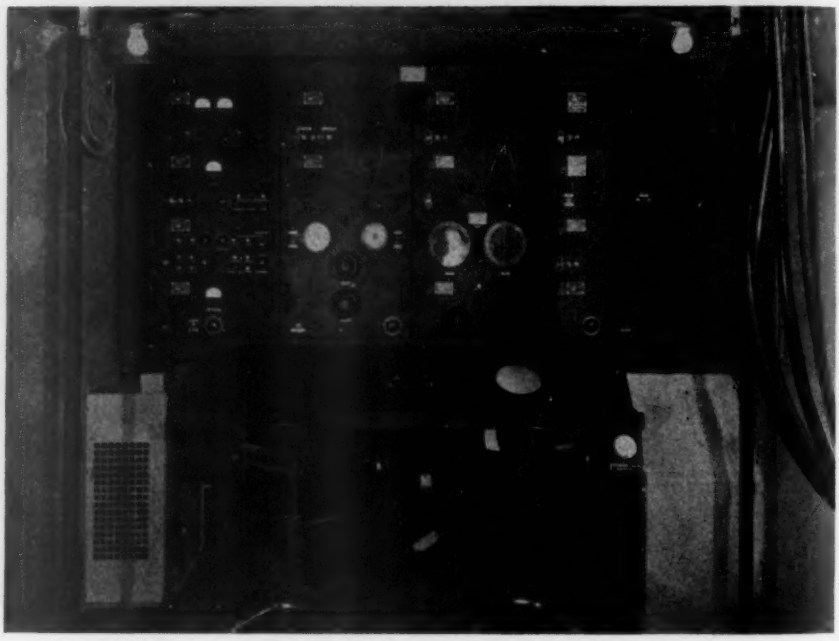


FIG. 17. Radio Set SCR-584. Indicator and control panel.

conical scanning. Pulses of 0.8 microsecond duration are transmitted at a repetition frequency of 1,707 p.p.s. (pulses per second).

While the SCR-584 is one of the most successful and versatile radar equipments ever produced, its size and weight limit its applicability in assault operations, particularly those involving beach landings. To fulfill that tactical requirement, the SCR-584 was repackaged into a smaller watertight trailer having a lower silhouette and capable of being floated ashore. This set known as the SCR-784 is shown in Fig. 18. With few exceptions, its electrical and performance characteristics are identical to those of the SCR-584. The main control panel, located at the rear of the trailer, and inclosed by a canvas tent, is shown in Fig. 19.

FIG. 18. Radio Set SCR-784 in operation on trailer K-84 (Roadside view).

The set is serviced through two watertight hatches located on top of the trailer.

In addition to antiaircraft gun laying there exists a tactical requirement for radar coastal fire control against water-borne targets. Radar Set AN/MPG-1 was developed for that application. A phantom view of the set is shown in Fig. 20. Extreme accuracy and high target resolution, as well as provisions for surveillance, were necessary to meet the

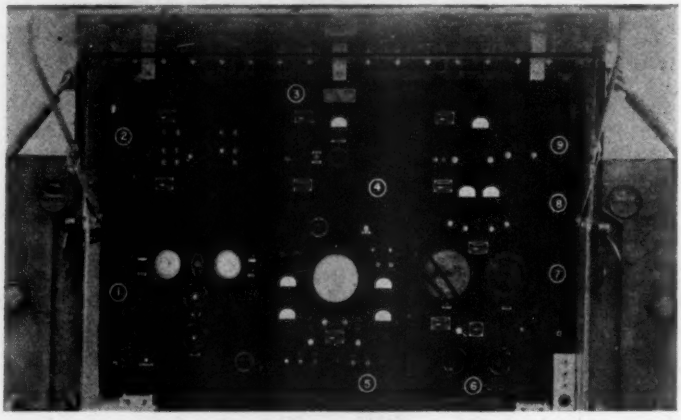


FIG. 19. Radio Set SCR-784 main panel (Showing operator's controls). 1. Range indicator BC-1371; 2. Range unit BC-1062-C; 3. Receiver BC-1056-C; 4. Plan position unit BC-1058-C; 5. Indicator control unit BC-1370 with indicator BC-1092-C; 6. Control unit BC-1085-A; 7. Indicator BC-1076-A; 8. Tracking unit BC-1090-C; 9. Tracking unit BC-1086-C.

military requirements. To obtain the desired performance the set was designed to operate at 3 cm. wavelength, using a one-microsecond pulse with a repetition rate of 1,024 pps. for surveillance and one of 0.25 microsecond at a rate of 4,079 pps. for tracking. It uses a magnetron oscillator with 60 kw. peak output which is transmitted by waveguide to a Schwarzschild antenna having a folded horn and parabolic reflector, and fed by a rotating feed arm to produce rapid scan over a 10 degree

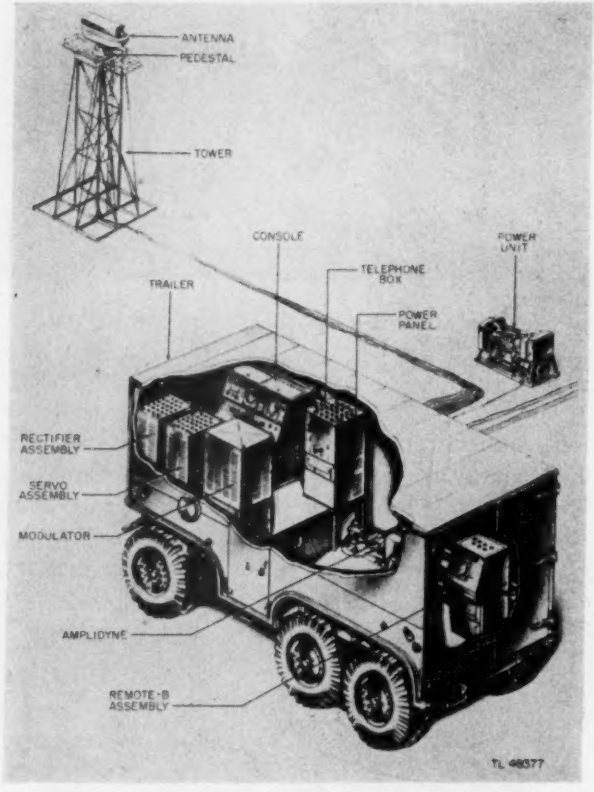


FIG. 20. Radar Set AN/MPG-1. Phantom view of operations trailer. Showing antenna and power unit in operating position.

azimuth sector. The AN/MPG-1 has a search range of 80,000 yards and is capable of accurately tracking targets at ranges from 500 to 28,000 yards with range accuracy of ± 5 yards and azimuth accuracy of ± 0.02 degree.

The indicator includes a PPI oscilloscope for general surveillance and two *B-scan* scopes for tracking and shell spotting, respectively. Range and azimuth data are fed to an appropriate gun director by potentiometers.

While the radar sets briefly described herein are important examples of equipments developed to do specific jobs for the Army Ground Forces, they represent only a small number of the many tactical applications which have been successfully fulfilled by radar. Most of the sets mentioned have been adapted to other tactical uses by field modifications, thereby proving again radar's great versatility.

CONCLUSION.

Radar, which was ready for very limited operational use at the outbreak of World War II, will undoubtedly be regarded as one of the great technological developments of this generation. Its full potentialities, both as an instrument of war and for peacetime application, have not been realized as yet. New technical advances in the art and new tactical procedures are being developed regularly, while planning for its peacetime use is just now beginning. The future of radar seems particularly bright.

Full Value From Peanuts.—Progress toward fully utilizing the peanut has been announced by the U. S. Department of Agriculture in reporting the results of laboratory scale experiments at the Southern Regional Research Laboratory at New Orleans where research on the utilization of this crop is under way. The new byproduct is a variety of feed yeast that has proved of value in livestock and poultry feeding. The process also lessens a sewage disposal problem.

When oil is extracted from peanuts, the high protein meal remaining is valuable as a livestock feed, but research has shown that it may be even more valuable for industrial uses in which the purified protein is used for tacky and remoistening adhesives, and for coatings, sizings and fibers. After the protein is separated from the meal, a waste liquor remains which may contain one per cent. of sugars. Such a liquor ferments and is likely to be a nuisance in streams, causing odors, and killing fish by exhausting oxygen in the water.

But by controlling this fermentation in a tank—sterilizing the liquor, and then inoculating it with the food yeast, Torulopsis utilis—disposal is simplified and the sugars are converted into a protein feed product valuable for its vitamin content.

This yeast has also been used successfully in fermenting similar liquors from sweetpotato starch mills. The addition of a nitrogen salt to the waste liquor improves the growth of the yeast. The laboratory work indicated that the fermentation would do well as a continuous process with waste water feeding into the tank and the yeast being removed as it grew.

At the other end of peanut utilization, the Department's Northern Regional Research Laboratory at Peoria, Ill., has discovered that ground peanut hulls combined with certain other materials are satisfactory for the manufacture of a cork substitute manufactured in sheets or for molding into crown caps for bottles.

R. H. O.

A STUDY OF SURGING IN FAN OR COMPRESSOR SYSTEMS.

BY

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ABSTRACT.

An analytical study is presented which explains the cause of one type of surging in a system connected to a fan or compressor. Surging occurs in an unstable region in which the fan pressure rises with an increase in capacity. Surging does not occur in a stable region in which the fan pressure decreases with an increase in capacity. The ratio of vibration pressure amplitude to particle velocity is greater in the unstable region than in the stable region. At critical conditions the pressure wave is in phase with the velocity wave. For a given particle velocity, the pressure amplitude in the unstable region is greater than the pressure amplitude in the stable region. A criterion for no surging is given.

The flow is steady, or practically so, in many installations of a fan or compressor and connected piping. Cases have been reported, however, in which a marked periodic fluctuation has been superposed upon the main steady flow. This fluctuation has been called "surging" and "pumping." In some cases of centrifugal compressors and superchargers the surging is a very important factor; it may become dangerous, and it may limit the useful range of operation of a machine. Some features of the action have been established, but no complete explanation of the cause has been published. Stodola (1),[1] for example, gives some details about surging but he does not fully explain the action. The main purpose of the following is to present an analytical discussion which explains the cause of one type of surging.

It is difficult to obtain complete data about various surging installations. Two necessary conditions, however, seem to be fairly well established for one type of surging. First, this surging occurs when operation is in a region in which the fan or compressor characteristic shows an increase in pressure with an increase in volume rate of flow. Surging does not occur when the fan or compressor characteristic shows a decrease in pressure with an increase in capacity. Secondly, surging occurs when the volume of the connected system is relatively large.

Figure 1 shows diagrammatically the characteristic of a fan or compressor and the connected system. In each sketch the abscissa is the capacity or volume rate of flow. In Fig. 1a the ordinate is the pressure developed by the fan. The characteristic curve is given for a constant angular speed of the rotating impeller. As the capacity increases the pressure first increases, reaches a peak, and then decreases.

[1] Numbers in parentheses refer to the Bibliography at the end of the paper.

Figure 1b shows the characteristic for a connected piping or system. The ordinate is the pressure drop in the system. There may be fixed resistances together with piping and chambers. For piping the pressure drop increases as the velocity of flow increases. If the pipe friction coefficient is constant and the flow is turbulent, then the pressure drop varies as the square of the flow velocity.

Figure 1c shows two possible combinations of fan and system. For the system characteristic No. 1 the point of operation is at point *A*,

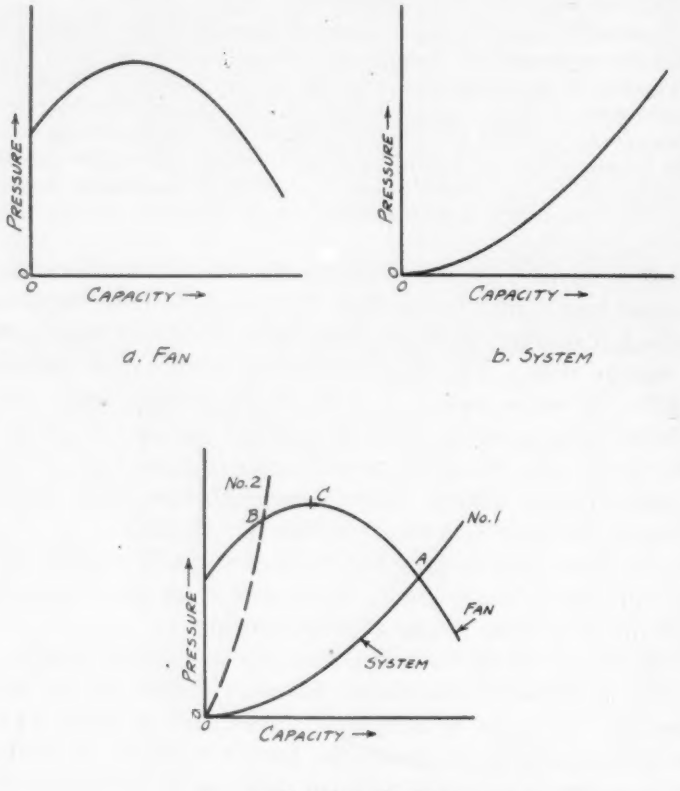

FIG. 1. Characteristics of fan or compressor and system.

the intersection of the two curves. Experience shows that this is a stable point of operation; surging would not persist if the steady flow were temporarily disturbed. If the system characteristic were that represented by No. 2, operation would be at point *B*, an unstable condition. Stodola (1) states that the region of capacity below that at the peak *C* is unstable.

It is difficult to determine the cause of stable or unstable operation solely from a diagram of the type shown in Fig. 1c. Such a diagram

may be useful in formulating a simple final rule, but by itself it does not completely explain the action.

Imagine an arrangement of a single mass connected to one end of a single spring. Assume that the other end of the spring is fixed, and that the mass has a single degree of freedom. With or without friction, it is difficult to imagine how the mass could possibly have an unstable free oscillation. It appears essential to have some other element acting on the system, as an external force, in order to have an unstable oscillation. Thus, considering free oscillations, it seems impossible to have an unstable fan by itself, or an unstable system of piping by itself. In each case, with friction the free oscillation is stable. But a combination of fan and system may be unstable if there is a certain coupling of the two.

Surging cannot be explained adequately in very simple terms because the action, like many vibratory actions, is quite complicated. Many different factors are involved, each of which is essential to the complete phenomenon. For example, one might be tempted to make an analysis neglecting friction. Such a study would be interesting in illustrating certain critical values, but it would not explain some of the results found in practice, results which are caused by friction, and which are of practical importance.

VIBRATION OF FLUID IN A CYLINDRICAL PIPE.

Before studying the combination of fan and system, consider first the action of a simple system, the vibration of a compressible fluid in a long cylindrical pipe, with the vibration along the axis of the pipe. The following notation will be used:

c velocity of pressure wave, or acoustic velocity,
D ω/c,
F attenuation factor due to friction, damping of vibrations per unit distance along wave travel,
f frequency of vibration, cycles per unit time, $f = \omega/2\pi$,
i $\sqrt{-1}$,
L length of pipe,
p excess pressure, or pressure above equilibrium or mean pressure,
x distance along pipe from driving piston,
y longitudinal particle displacement, or displacement of a particle, in the path of a pressure wave,
$\frac{dy}{dt}$ particle velocity,
t time,
ω circular or angular frequency, radians per unit time, $\omega = 2\pi f$,
ρ density of fluid, mass per unit volume.

The term "excess pressure" should not be confused with "fan pressure" or "pressure" in the pipe at steady flow conditions. Excess

pressure is a pressure due to the vibration of the compressible fluid. Excess pressure is the pressure superposed on the steady flow mean pressure. The term "particle velocity" should not be confused with linear velocity of steady flow. Particle velocity is a velocity due to the vibration of the fluid; it is a velocity superposed on the steady flow velocity. The steady flow velocity may be zero or some value different from zero.

Figure 2 illustrates the notation. At each end of the pipe of length L is some terminal element or combination of elements. The terminal element is represented by a piston. For a closed end the piston is fixed; for an open pipe there is no piston. The piston at the driving or left end will be taken as the origin.

Assume that the driving piston sends pressure waves through the fluid down the pipe at a constant angular frequency ω. As a single wave travels along the pipe its amplitude decreases with respect to distance; there is an attenuation or damping of the wave due to friction.

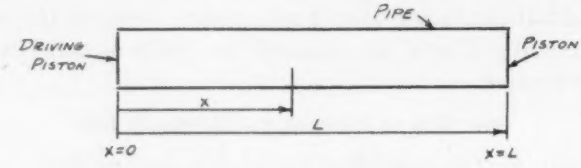

FIG. 2. Notation for vibration of fluid in pipe.

The piston at the other end is controlled solely by the fluid and its own vibration characteristics. Consider the action at a distance x from the origin. A composite wave train will travel from the origin in the positive direction because of the recurrent reflection in the tube. Each component of this train will differ from the others in having a different amplitude at the start, and a different phase depending upon the number of times the component has traversed the double length of the pipe.

The particle velocity for the waves travelling in the positive direction to the right can be expressed in the form of a series

$$\left(\frac{dy}{dt}\right)_{+} = \sum_{m=1}^{\infty} A_m' e^{-(2mL+x)F} e^{-i\left(\frac{2m\omega L}{c}+Dx\right)} e^{i\omega t}, \tag{1}$$

where F is an attenuation factor, m is an integer, each A' is a constant, c is the velocity of the pressure wave, and $D = \omega/c$. Since the amplitudes and phases of all the components follow the same general relation, the components can be lumped into one wave of the type

$$\left(\frac{dy}{dt}\right)_{+} = Ae^{-(F+iD)x}e^{i\omega t}. \tag{2}$$

The constant A includes all of the series of coefficients of Equation (1).

At the station x there is a reflected wave from the righthand piston at $x = L$; this wave travels towards the left in the negative direction. At the station x the particle velocity for the wave train in the negative direction is

$$\left(\frac{dy}{dt}\right)_{-} = -Be^{(F+iD)x}e^{i\omega t}, \tag{3}$$

where B is a constant formed in a manner similar to that for A. The net particle velocity at any point in the pipe is thus

$$\frac{dy}{dt} = [Ae^{-(F+iD)x} - Be^{(F+iD)x}]e^{i\omega t}. \tag{4}$$

The instantaneous excess pressure p, or the pressure above the equilibrium or mean value, is given by the relation

$$p = \pm c\rho \frac{dy}{dt}, \tag{5}$$

where the plus sign refers to the wave in the positive direction and the minus sign refers to the wave in the negative direction. The derivation of Equation (5) can be found in any number of reference books, as that by Crandall (2). The total excess pressure at any point in the pipe can be then written in the form

$$p = \rho c[Ae^{-(F+iD)x} + Be^{(F+iD)x}]e^{i\omega t}. \tag{6}$$

It is useful and convenient to employ the concept of "impedance" which is a concise measure of pertinent factors in the vibratory motion. Impedance is defined here as the ratio of excess pressure amplitude to particle velocity amplitude. Amplitude refers to the maximum value in the vibration. Impedance is a complex number. Its absolute magnitude is the amount of excess pressure produced by unit particle velocity; the impedance angle is the angle by which the excess pressure amplitude leads the particle velocity amplitude.

The driving piston by itself has an impedance Z_0 and the piston at $x = L$ has an impedance by itself of Z_L. The driving point impedance at $x = 0$ is Z_{00}. The constants A and B in the foregoing equations can be evaluated from the boundary conditions. The final important result can be arranged in the form

$$Z_{00} = \frac{(Z_0 + \rho c)(Z_L + \rho c) - E^2(Z_0 - \rho c)(Z_L - \rho c)}{(Z_L + \rho c) - E^2(Z_L - \rho c)}, \tag{7}$$

where $E = e^{-(F+iD)L}$. The intermediate steps involved in arranging Equation (7) can be found in Crandall (2). The mathematics for the vibration of a compressible fluid in a pipe is identical to that in certain electrical transmission line problems.

Two special cases may help to bring out some of the physical significance of Equation (7). Assume no friction, $F = 0$, $Z_0 = 0$, and $Z_L = 0$. Then Equation (7) reduces to

$$Z_{00} = i\rho c \tan \frac{\omega L}{c}. \tag{8}$$

The driving point impedance is purely imaginary, or the excess pressure amplitude is 90 degrees ahead of the particle velocity amplitude. The driving point impedance is zero when $\omega L/c$ is π radians or some integral multiple of π radians. The lowest natural frequency, or resonant frequency, f, in cycles per unit time becomes

$$f = \frac{c}{2L}. \tag{9}$$

This familiar result for a pipe open at both ends is frequently presented in elementary discussions in physics.

Next, assume that $F = 0$, $Z_0 = 0$, and that Z_L approaches infinity because of a closed end. Then Equation (7) reduces to

$$Z_{00} = -i\rho c \cot \frac{\omega L}{c}. \tag{10}$$

The lowest natural frequency is realized when $\omega L/c$ is $\pi/2$ radians, namely

$$f = \frac{c}{4L}, \tag{11}$$

a familiar result for a pipe open at one end and closed at the other.

The two foregoing special cases are simplifications, because in practice there is friction, excess pressure and particle velocity amplitudes are not infinite, and there is an end effect at an open pipe end which requires a correction for the effective length of the pipe.

COMBINATION OF FAN OR COMPRESSOR AND PIPE.

Imagine a combination of a fan or compressor connected to a single long cylindrical pipe. Assume that the terminal impedance Z_L is zero, and that the velocity of fluid flow is small in comparison with the velocity of the pressure wave. Then the driving point impedance can be expressed as

$$Z_{00} = Z_0 + \rho c \tanh \left[FL + i \frac{\omega}{c} L \right]. \tag{12}$$

Each term will be treated separately before discussing the combination.

It seems reasonable to regard Z_0 as real, and directly proportional to the slope of the fan characteristic curve of pressure versus capacity. This means that the action of the driving piston by itself is one in

which the pressure wave is in phase with the particle velocity wave. For a connected pipe of constant diameter the fan pressure versus capacity curve can be converted to a curve of fan pressure versus linear flow velocity. The slope of this fan pressure-velocity curve at a particular velocity of flow gives the value of Z_0 at that flow. A positive value of Z_0 would result if the slope of the characteristic curve were positive, that is, if there were an increase in fan pressure with an increase in capacity. A negative value of Z_0 would result if the slope were negative, that is, if there were a decrease in fan pressure with an

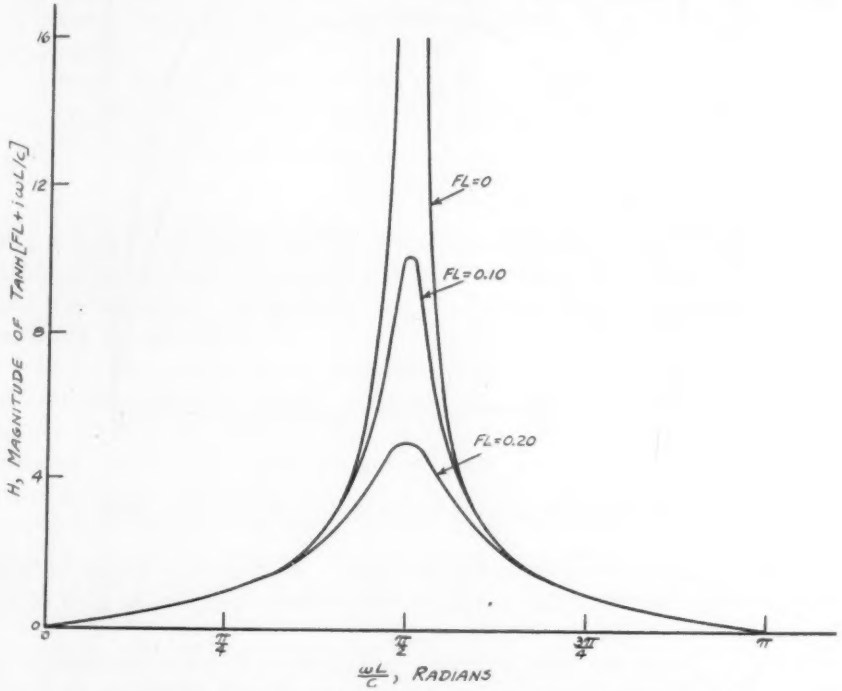

FIG. 3. Magnitude of tanh $[FL + i\omega L/C]$ for different values of FL.

increase in capacity. This notation may or may not agree with that sometimes used in fan engineering, but this present notation is necessary in order to keep the analysis clear and consistent.

Kennelly has prepared excellent charts (3) and tables (4) of complex hyperbolic functions which are very convenient for engineering calculations. The hyperbolic tangent in Equation (12) can be expressed in the exponential form

$$\tanh\left[FL + i\frac{\omega L}{c}\right] = He^{i\theta},$$

where H is the magnitude and θ is the polar or phase angle. Figure 3

shows a plot of the magnitude of the hyperbolic tangent for several values of FL. When $\omega L/c$ is $\pi/2$ radians the magnitude H reaches a maximum value; for a given particle velocity amplitude the excess pressure amplitude is a maximum. This maximum value decreases as the friction increases. Figure 4 shows a plot of the phase angle of the

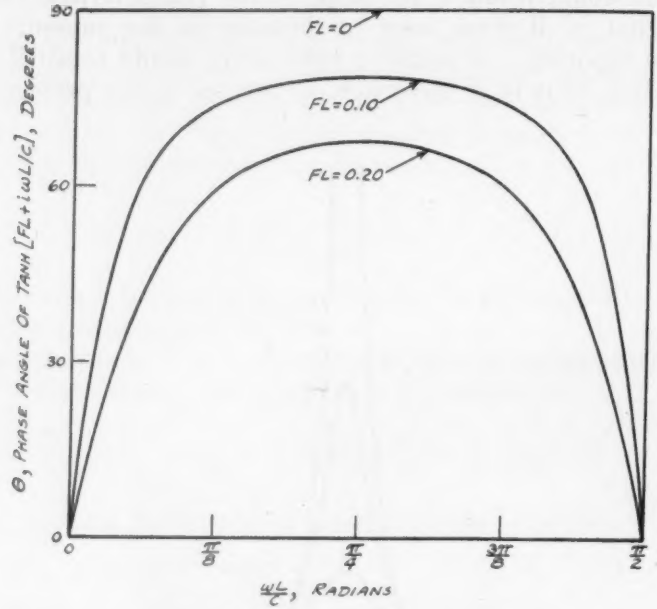

FIG. 4. Phase angle of tanh $[FL + i\omega L/C]$ for different values of FL.

hyperbolic tangent for several values of FL. When $\omega L/c$ is $\pi/2$ radians the phase angle is zero, that is, the excess pressure amplitude is in phase with the particle velocity amplitude.

Figure 5 shows the characteristic curve for a fan or compressor in terms of fan or compressor pressure developed as a function of linear velocity in the connected pipe. The pipe offers such a resistance to

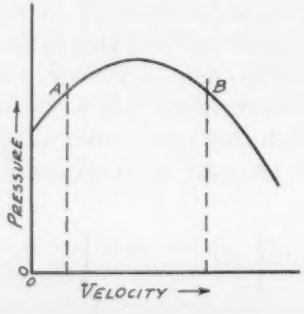

FIG. 5. Fan characteristic.

the flow that the point of operation is at point A, at a velocity of flow lower than that at the peak fan or compressor pressure. The slope of the curve at A gives the numerical value of Z_0; the sign is positive. When Z_0 is positive and $\omega L/c$ is $\pi/2$ radians the driving point impedance has a maximum real value

$$Z_{00} = Z_0 + H. \tag{13}$$

Impedance is the ratio of excess pressure amplitude to particle velocity amplitude. For a given particle velocity amplitude the excess pressure amplitude is a maximum. If the friction is small and/or the value of Z_0 is very large, the excess pressure amplitude may be appreciable and noticeable.

When operation is at a flow higher than that at the peak fan or compressor pressure, as at point B in Fig. 5, the value of Z_0 is negative. The driving point impedance is

$$Z_{00} = -Z_0 + H. \tag{14}$$

For a given particle velocity amplitude the excess pressure amplitude for a negative Z_0 is less than that for a positive Z_0. With a negative Z_0 the driving point impedance may be zero which means zero excess pressure amplitude.

The two preceding paragraphs refer to a given particle velocity amplitude, and this raises a question as to the nature of the vibrator or source producing the vibration. There are various types of vibrators. Surging can be explained most easily by a velocity type vibrator, that is, one which impresses a certain particle velocity amplitude on the connected system regardless of the impedance of that system. This particle velocity vibration might be due to angular speed variations of the fan or compressor impeller. The actual particle velocity wave may have a very complex shape. This complex wave, however, can be broken up into components. The wave shape can be expressed in terms of a Fourier series. The components having a frequency close to or coinciding with the critical frequency of the system develop the greatest excess pressure response because this critical frequency corresponds to the highest impedance for the system.

A comparison of driving point impedances seems to play a basic role in explaining the cause of one type of surging. This explanation gives results which are consistent with observations. For example, there are indications that surging is more pronounced with centrifugal compressor than with fans. In a centrifugal compressor developing a relatively high pressure at a low capacity, the value of Z_0 in the unstable region may be much higher than that for a fan developing a relatively low pressure and a high capacity. The higher value of Z_0 for the compressor means a higher excess pressure amplitude for the same particle velocity amplitude.

The excess pressure amplitude depends upon the friction or attenuation factor. There is a definite lack of experimental data on attenuation factors. Helmholtz and Kirchoff (2) developed a theory for the damping of small amplitude vibrations of a fluid in a cylindrical tube. Their work assumed laminar motion, and gave values which are very low for moderate and large excess pressure amplitudes. Binder (5) modified the Helmholtz-Kirchoff theory by the addition of an eddy viscosity term to take into account inertia forces. This modified theory gives fair agreement with measured values of the damping of large excess pressure amplitudes for air and carbon dioxide. The final relation for calculating the attenuation factor is

$$F = \frac{2}{dc}\left[\frac{\omega}{2}\left(\frac{\mu}{\rho} + \frac{\epsilon}{\rho} + \frac{k}{\rho a}\right)\frac{1}{2\pi}\right]^{\frac{1}{2}}, \tag{15}$$

where d is pipe diameter, μ is dynamic viscosity of the fluid, ϵ is eddy viscosity, k is thermal conductivity of the fluid, and a is the specific heat of the fluid at constant pressure.

Surging occurs when the volume of the connected piping is relatively large. A relatively large volume can be realized with relatively long pipes and large diameters. Equation (15) shows that the attenuation factor F is inversely proportional to the pipe diameter. A large pipe diameter means a small F. Figure 3 shows that a small F means a large pressure amplitude. A relatively long pipe means a relatively low surging frequency. As the pipe length decreases the critical surging frequency increases. Equation (15) shows that the damping factor increases as the frequency increases. At a high frequency the damping may be so great that the surging is not noticeable. Also, the surging may not be noticeable with a short pipe length because the ear or some pressure instrument does not respond well to the high frequency.

The foregoing discussion dealt with the case in which $Z_L = 0$. Other values of Z_L are possible. For a rigid closed end Z_L approaches infinity. A discussion with other values of Z_L could be given to explain the same general cause for surging.

SURGING FREQUENCY AND CORRECTION FACTORS.

For a pipe with $Z_L = 0$ a critical or surging condition is reached when $\omega L/c$ is $\pi/2$ radians. The critical surging frequency f is

$$f = \frac{c}{4L}. \tag{16}$$

Certain correction factors should be noted.

When Z_L is taken as zero, this does not mean exactly an open pipe of length L. When the pipe end is open, the reaction of the fluid outside on the fluid in the tube is a rather complicated function of

the frequency and of the shape of the opening. When the wavelength of the pressure wave is large compared with the radius of the pipe the pressure waves spread out in all possible directions from the open end. End corrections are worked out in various reference books on vibrations, as in the one by Morse (6). The correction to the length of pipe is about 0.85 times the pipe radius when the pipe has a flange, and the correction is about 0.6 times the pipe radius when there is no flange. The effective length L equals the actual length plus the end correction.

The foregoing study was based upon the assumption that the velocity of flow in the pipe was small in comparison with the velocity of sound. The velocity of sound in still air is about 1,120 feet per second for standard conditions of atmospheric pressure and temperature. In some cases this assumption may not be accurate. General rules for determining the exact effect of flow velocity are difficult to formulate. Some preliminary studies, as those by Trimmer (7), indicate that the driving point impedance and the surging frequency may be reduced as the flow velocity is increased.

METHODS FOR ELIMINATING SURGING.

With a by-pass to waste on the discharge side of the fan, it is possible to operate the fan at a capacity above that for the peak pressure and thus eliminate surging. A system may not receive all the capacity delivered by the fan.

Besides throttling and introducing friction, the surging might be reduced or eliminated by a properly proportioned resonator consisting of a small short tube and a large chamber connected as a side branch to the pipe. This arrangement is frequently called a Helmholtz resonator. The resonator acts as a weak spring and mass combination.

It would be desirable to form a definite criterion for a condition of no surging. No surging would occur if the driving point impedance Z_{00} were zero. For a pipe with $Z_L = 0$, Equation (14) shows that no surging would occur if

$$-Z_0 + H = 0. \tag{17}$$

The main difficulty in evaluating H is to obtain an accurate value of the attenuation factor F.

From one point of view, the no surging criterion of zero driving point impedance is conservative. A small impedance, and therefore a small excess pressure amplitude, may be allowable if the surging were not audible to the ear or if the surging were less severe than the vibration caused by other sources.

OTHER POSSIBLE CAUSES OF SURGING.

Surging may develop if fluid separates from the blades of the impeller, or if stalling occurs. The separation may be periodic.

At very high velocities a periodic compressibility effect might occur. At some low pressure region on the blade the fluid velocity may approach the velocity of sound; a compression shock may form. A periodic formation and collapse of this shock may cause surging.

Surging may occur when the fan or compressor characteristic curve coincides with the system characteristic over a range of capacities. In such a case there is no definite point of operation, and a hunting may result.

Surging may also occur because of a periodic variation in the system or load. For example, if a flat plate or cylinder were in a stream, a trail of alternate vortices may leave the rear of the object. A vortex may develop at one edge, pass downstream, and then another vortex may develop on the other edge. A periodic action of this sort may be so coupled as to cause a surging in the system.

The writer is deeply grateful to Mr. H. F. Hagen of B. F. Sturtevant Co., to Mr. Walter R. Elliott of Buffalo Forge Co., and to Mr. L. C. Smith of the Spencer Turbine Co., for general information regarding necessary conditions for surging.

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NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

REFERENCE FUEL SCALES FOR KNOCK RATING.

In a paper presented at the winter meeting of the Society of Automotive Engineers in Detroit on January 11, 1946, Donald B. Brooks, chief of the Bureau's Automotive Section, reviewed the development of knock rating scales and described a new reference fuel made up from various proportions of triptane and normal heptane. He pointed out that today the antiknock quality of motor fuels is the outstanding characteristic by which they are graded. The average motorist realizes that when he pays more for a premium motor fuel, he is buying higher antiknock quality than is available in regular gasoline. Many even have at least a practical understanding of the term "octane number" by which this quality is now expressed.

A quarter of a century ago, the first yardstick for measuring the antiknock quality of fuels was brought forth in England by H. L. Ricardo. He designed an engine, the compression ratio of which could be varied so as to cause knocking with any fuel then available. The point at which this occurred was called the highest useful compression ratio, abbreviated HUCR, and was used as a measure of the antiknock quality of the fuel.

As interest in knock rating spread, many laboratories used engines conveniently at hand in making their determinations. These varied from small engines designed to power farm-lighting plants to complete automobile and truck engines, and single cylinders of airplane engines. A variety of test procedures were used, and the results frequently were expressed in terms of the blend of high and low reference fuels equalling the test fuel in knock. As there was no uniformity either of test engine, test procedure, or reference fuels used, the results were meaningless except to the laboratory of their origin.

An urgent demand, therefore, arose for standardizing the essential details of knock rating. Under the direction of the Cooperative Fuel Research (CFR) Committee, a test engine was developed and standardized. After considerable study and discussion, the present octane-number scale was adopted. Isooctane, produced at the rate of millions of barrels a month as a large constituent of the aviation fuel that powered the recent war, was unknown 20 years ago. First prepared in 1926, it was found to be of much higher knock rating than any fuel of that time. Blended with normal heptane, a hydrocarbon poorer in

* Communicated by the Director.

knock rating than any fuel then used, it formed the octane-number scale. In this scale, the percentage of isooctane in blend with normal heptane which, in the standard engine, gives knock equal to that of a test fuel is called the octane number of the test fuel.

This scale has proved satisfactory for the knock rating of motor fuels, and naturally was soon applied to the rating of aviation fuels as well. When improvement in such fuels made them superior in antiknock quality to isooctane, the scale was physically extended by adding the powerful knock suppressor tetraethyl lead to isooctane, and knock ratings were expressed in terms of the amount of tetraethyl lead added to isooctane to equal the test fuel in antiknock quality. The resulting break in the knock-rating scale at 100 octane number, however, has been very troublesome. Many attempts have been made to extend the scale, and two or three have gained limited acceptance.

For some years, a panel of the CFR Aviation Fuels Division has been making an investigation of reference-fuel scales. After extensive research, it is now proposed to define a new scale in terms of blends of triptane, a relatively new compound of exceptionally high knock rating, and normal heptane, to both of which will be added about one-tenth of one percent of tetraethyl lead. Such a scale will cover the range from below present motor fuels to well beyond present and foreseeable future aviation fuels. If need be, it can be further extended readily and logically to the upper limit of antiknock quality. It is also proposed to express knock ratings in terms of "triptane number," analogous to octane number, for fuel blending work, and interchangeably in terms of a "Detonation Index" for engine work.

MOISTURE CONDENSATION IN BUILDINGS.

House owners who insulate their dwellings are apt to think that the attendant saving in fuel is an unmixed blessing. However, experience has shown that in many cases insulation of walls, particularly in houses already built, raises problems of moisture condensation that must be seriously considered.

Condensation of moisture in buildings has been found in many cases to involve deterioration, and the Bureau has received numerous requests for assistance in providing remedies. There are three major problems, namely: Condensation on windows causing deterioration of window frames, sills, and wall construction underneath; condensation in crawl spaces causing rusting of metal floor beams, pipes, etc.; condensation in wall and roof construction with attendant loosening of plaster, rotting of wooden members, and deterioration of the insulation itself. A study of specific condensation problems is being made in housing projects in Washington, Dayton, Paducah, Cleveland, Detroit and other cities so that corrective measures can be adopted and certain

principles of building construction laid down for the guidance of Federal Housing Agencies. The results will be made available to the public in the near future.

SPECIFICATION OF RAILROAD SIGNAL COLORS AND GLASSES.

The use of colored lights as signals is almost universal in railroad, highway, marine, and aviation traffic or navigation. To insure that only colors of the proper hue and strength are supplied to the carriers, all parts of purchase specifications dealing with color should rest on a sound and workable basis—suitable for use both by the standardizing laboratory and the inspector, purchaser, or manufacturer.

In 1931, the Signal Section of the Association of American Railroads began a study that led to improved methods of selecting signal colors. As rapidly as the colors were chosen, Corning Glass Works duplicated them in glass. These master standards were then turned over to the Bureau, where they were carefully measured. The result is a set of specifications to be used in the purchase of railroad signal glassware, covering the railroad signal colors, red, yellow, green, blue, purple and lunar-white.

Duplicates of the master standards, defining the limits of transmission and chromaticity permissible for such glassware, are sent to the Bureau for comparison with the master standards. They may then be purchased by anyone requiring such duplicates, together with a certificate showing how closely they conform to the master standards.

The Bureau's part in this work is described in two papers. The first was published in *J. Research N.B.S.*, **22**, 627 (June 1939) (RP1209), and sets up the luminous-transmission scale used in the specification of railroad signal glasses; it helps to insure that the glassware transmits enough light for the purpose. The second paper will appear in the January 1946 number of the *Journal* (RP1688). It is entitled Specification of Railroad Signal Colors and Glasses, by Kasson S. Gibson, Geraldine Walker Haupt, and Harry J. Keegan. This paper provides the basis for insuring that the signal colors seen by trainmen will fall within the ranges found by the signal engineers to be best adapted to safe operation of the railroads.

HELIOGRAPHIC SIGNALING MIRRORS.

A pocket-size mirror will reflect flashes of sunlight readily visible to an observer sometimes as much as 10 miles away. Because of this power of a small, inexpensive device to attract attention at considerable distances, all branches of the American armed services now equip life boats, rafts, and floats with heliographic signaling mirrors, each having some means for a signaler to aim the sunlight flashes from it. These mirrors have passed through several stages of development.

The earliest aiming device was a small screen to be held in front of part of the mirror and used to align the reflected beam of light. In 1942, a better method of aiming was worked out by L. L. Young of the Bureau's staff, but this required simultaneous observations of a distant target and of a nearby image in the rear of the mirror. Several months later, C. H. Learned of Carmel, California, suggested to the National Inventors Council that a retroreflector of one of the types widely used in night-visible traffic signs be fastened behind the clear window of a metal-on-glass mirror. Because part of the light returned toward the sun by the retroreflector thus placed is reflected rearward by the glass surfaces of the window, a signaler looking past the edge of the reflector through the window can see an imperfectly formed image of the sun in the direction in which the mirror is reflecting sunlight. Aiming such a mirror is merely a matter of turning it so as to place this bright spot (usually colored red by the retroreflector) upon the target.

R. S. Hunter of the Bureau's Photometry and Colorimetry Section has developed, with the aid of manufacturers, two models of the improved type of signaling mirror suggested by Mr. Learned. In the first, a flat retroreflector is tilted at about 30° behind the mirror window. In the second, a flat washer of retroreflective material is held by a cover glass against the rear of the window. The first mirror must always be rotated in its own plane until the retroreflector faces roughly toward the sun before the red aiming spot can be seen, but the second does not have to be so oriented. This washer-type retroreflector mirror is the easiest of all the types to operate and its general adoption as a signaling device for inclusion in life-boats, life-rafts, and life-vests is therefore recommended.

ATTACK ON REFRACTORY CLAY POTS BY OPTICAL GLASS.

Optical glass is manufactured at the Bureau in refractory clay pots, each of which holds from 1,000 to 2,000 pounds, depending on the density of the glass. The pots are placed in melting furnaces and held at temperatures between 1350° and 1450° C. for 8 to 20 hours. Reactions always occur under these conditions along the pot-glass interface. These reactions may become of sufficient magnitude to affect the quality of the glass and to seriously damage the pot, which in some instances may fail to hold the glass. Consequently, a study was made of samples of pot bottom before and after the production of glass to determine the manner and extent of attack on the refractory by optical glasses of different compositions and to identify the accompanying reaction products. The results of this study are reported in a paper (RP1689) by W. H. Parsons and H. Insley, in the January number of the *Journal of Research*.

Visual examinations were made of approximately 200 pots of lined

and unlined types used in the manufacture of barium crown, barium flint, light crown, borosilicate crown, and several different flint glasses. Samples from the bottoms of 62 of these pots were examined further with a petrographic microscope. Samples which were badly cracked and penetrated by glass were selected in most instances because they probably showed most clearly the effects of pot attack.

The occasional penetration of the bottoms of unlined pots by corrosive optical glasses was due in large part to the size, elongated shape, and vertical orientation of the pores in the refractory. With barium glasses, such penetration extended to a depth of 2 or 3 inches, but with borosilicate crown and most flint glasses it did not exceed about ½ inch. Pots containing barium glasses occasionally leaked in the melting furnace. Lined pots, however, were not penetrated by any type of glass except when the relatively dense lining was cracked in the bottom.

The corrosive action of barium glasses greatly enlarged the pores in the refractory and caused them to become connected, thus forming a system of branching channels. Borosilicate crown and most flint glasses, however, were only slightly corrosive and, therefore, did not form channels.

The crystalline reaction products at the pot-glass interface of the different types of barium glasses were barium feldspar, alkali aluminum silicates, and cristobalite. In pot bottoms penetrated by these glasses, barium feldspar, barium disilicate, zinc spinel, mullite, and traces of cristobalite and corundum were formed. Alkali aluminum silicates, cristobalite, and corundum occurred at the pot-glass interfaces of borosilicate crown and flint glasses. Mullite and corundum were the only reaction crystals present in the refractory penetrated by these glasses, with the exception of a flint glass with 62 per cent. of PbO. One or more new lead aluminum silicates of undetermined composition, and a trace of metallic lead occurred with this glass.

The presence of two types of glass was characteristic of refractory penetrated by barium and some lead glasses. One type was a glass altered in composition and certain physical properties by the attack on the pot constituents. This glass contained numerous seeds formed by the entrapment of the air in the original refractory and, probably, also by the liberation of gas in the glass batch. The second type of glass bore a close resemblance to the melt.

EXTRACTION OF ALUMINA FROM CLAYS AND HIGH-SILICA BAUXITES.

As a result of investigations concerning the utilization of clays and high-silica bauxites for the production of alumina, two methods of possible commercial application have been developed at the Bureau

(*Technical News Bulletin 338* (June 1945)). One of these is applicable only to bauxites, the other to both bauxites and clays.

In the former method, a novel feature is the extraction of bauxites with a solution consisting of a mixture of sodium hydroxide and sodium chloride. When the salt is present in sufficient concentration, the amounts of silica contained in the resulting sodium aluminate solutions are much less than when extractions are made with the sodium hydroxide alone. This reduction is caused by the precipitation of silica from solution as the very slightly soluble compound sodalite, $3Na_2O.3Al_2O_3.6SiO_2.2NaCl$, rather than as the relatively soluble sodium aluminum silicate hydrate formed in the absence of salt. Other sodium salts, including the carbonate, nitrate, and bromide, give sodalite-type compounds with sodium aluminum silicate. The chloride and nitrate compounds are the most effective in reducing the silica content of sodium aluminate solutions.

Alumina and soda are recovered from the bauxite-extraction residues by a modified soda-lime-sinter method. Alumina is precipitated from the sodium aluminate solutions by carbon dioxide. In the combined processes, overall recoveries in excess of 90 per cent. of the alumina in high-silica bauxites are obtained.

In the other method, which is applicable to both bauxites and clays, the aluminous material is sintered at about 1300° C. with sufficient limestone to convert its alumina to calcium aluminate and its silica to dicalcium silicate. The sinter is then annealed by cooling it slowly from 1300° to 1200° C. The annealed sinter dusts to a very fine powder which requires no grinding. This material is extracted with a solution containing about 200 grams of Na_2CO_3 and 150 grams of NaCl per liter, and an extract containing 70 to 80 grams of Al_2O_3 and 1 to 2 grams of SiO_2 is obtained. By boiling the extract with a seed charge of synthetic sodalite, its silica content is reduced to not more than 0.1 per cent. of the alumina content. Alumina, suitable for the manufacture of aluminum by electrolytic reduction, is precipitated by passing carbon dioxide into the desilicated solution. About 95 per cent. of the alumina in the clay is recovered by this method. This is higher than any reported extraction from clay by other alkaline processes and is equal to or somewhat higher than recoveries obtained by acid extractions. Losses of soda are small. An outstanding advantage of the process is that all steps can be conducted at atmospheric pressure, whereas many other alkaline methods for the extraction of alumina require autoclave desilication.

In cyclical operation of each of the two processes, the spent solution from the alumina precipitation step is used in the treatment of a fresh batch of material. The complete description of this work will be published as RP1691, by E. P. Flint, W. F. Clarke, E. S. Newman, Leo Shartsis, D. L. Bishop, and Lansing S. Wells, in the January *Journal of Research*.

MASS SPECTROMETER AS A TOOL FOR RESEARCH.

The Mass Spectrometry Section of the Bureau is an outgrowth of war work that is being continued as a part of the regular organization. Extensive use is being made of the mass spectrometer as an instrument for the quick, convenient analysis of a wide variety of gases and volatile liquids. The sample required for analysis is very small—only a cubic millimeter of gas or vapor—and complex mixtures of closely related organic substances can be analyzed with speed and accuracy unattainable by conventional means.

The mass spectrometer has been used in connection with the Government synthetic rubber program for a variety of purposes, such as determining the composition of feed stocks and intermediates in the production of butadiene, ascertaining the losses of butadiene in vent gases, and finding the purity of isoprene, butadiene, styrene, and other monomers. The purity of specification grade butadiene can be found with a high degree of accuracy by measurement of the freezing point. On fourteen consecutive cross-check samples the per cent. of 1,3-butadiene found by the mass spectrometer agreed with that found by the freezing point within an average of 0.08 per cent.

The molecular structure of high polymers, such as synthetic rubber and plastics, is being studied by subjecting the polymers to thermal decomposition and analyzing the resulting products by means of the mass spectrometer. In a classical study of the thermal decomposition of natural rubber, conducted several years ago by the late Thomas Midgely, 200 pounds of crude rubber was broken down by destructive distillation in order to get enough of the decomposition products to separate and identify them by the then available means. In the current work a sample of only a few milligrams—a millionth as much as was required by Midgely—is decomposed in a few minutes in a very high vacuum and the analysis is made and computed within a day or two instead of several months. Furthermore, the use of so small a sample enables the products of decomposition to be removed from the heated zone and condensed by liquid air before secondary reactions can take place.

The original work supported the conclusion that natural rubber was a polymere of isoprene, although the actual recovery of isoprene amounted to only about 10.per cent. In the present study the avoidance of secondary reactions leads to the recovery of the order of 90 per cent. of isoprene from the decomposition products. The principal commercial synthetic rubbers and several of the more common plastics have been investigated by the present means and a report on the subject is in preparation.

Nile-Control Project.—(*Compressed Air Magazine*, Vol. 50, No. 8.) The heightening of the Aswan (or Assuan) Dam on the Nile River is proposed as one step in a scheme for providing greater flood protection in Egypt. If the dam is made higher, it will be the third time this has been done. As originally built in 1902 it had an elevation of 357 feet, was raised in 1912 to 374 feet, and again in 1933 to 403 feet. The current plans call for increasing its height to 439 feet and its impounding capacity from four million to more than seven million acre-feet.

It was suggested in 1932 that additional works be constructed to take care of Nile floods, but they were not undertaken because the river was in a cycle of predominantly low maximum flow. Meteorological data compiled since 1869 show that there are alternating periods of low- and high-flood values. During the first 30 years in which records were kept there were nineteen dangerous floods, while in the following 39, up to 1937, there were but six. Since then there have been three more, indicating that the high cycle is beginning.

All of Egypt is below the flood level of the Nile, so there is a strong demand for greater protection. In spring and summer the river stays within its own channel, but at other seasons it may rise 20 feet or more and all that then keeps it from overflowing are man-made banks that extend from Aswan Dam to below Cairo and thence along the two branches of the stream as it makes its way through the delta to the sea. In lower Egypt the river runs about 10 feet above ground level during ordinary high water, and from 2 to 4 feet higher during exceptional floods. A break anywhere in the levees would take hundreds or thousands of lives and do millions of dollars worth of property damage.

Raising the height of the dam also involves increasing its thickness. The first lift was added according to a plan devised by Sir Benjamin Baker. By means of it, a 6-inch gap, known as the Baker space, was left between the old and the new masonry, the two being tied together by means of steel rods. The gap was subsequently filled with clean, broken granite. Then, after a sufficient lapse of time to allow for settlement and the equalization of temperatures, the intervening space was thoroughly grouted to form a single monolithic structure. The second heightening was accomplished by dressing off the downstream face of the existing dam and constructing masonry buttresses in sliding contact with it. Non-corrosive steel plates were introduced to assist the sliding action. It is now proposed to demolish these buttresses and again increase the thickness of the structure by the Baker method.

In conjunction with the proposed work on the dam, it is planned to construct a channel from Aswan Reservoir to a neighboring large depressed area, the Wadi Rayan, and use the latter as a storage space for excess water.

R. H. O.

THE FRANKLIN INSTITUTE.

ANNUAL MEETING, JANUARY 16, 1946.

Mr. Charles S. Redding, President, presided at the annual meeting of The Franklin Institute, and called the members to order immediately following the playing of the National Anthem.

The President announced that this meeting is designated as the Annual Meeting of The Franklin Institute and requested members to approve minutes of the November meeting, which appeared in full in the December JOURNAL. There being no dissent, the minutes were declared approved as printed.

The Secretary, Dr. Henry Butler Allen, was called upon. From the Membership Department he reported the following new admissions:

Sustaining	1
Active	46
Associate	31
Student	36
Total	114

Two new Firms have taken Library Sustaining Memberships, making a total of 89 Firms and 763 people in this category.

Total Membership as of December 31, 1945 5,449

Dr. Allen stated that in accordance with the By-Laws Tellers had been appointed to report upon election returns, inasmuch as officers and one-third of the Board of Managers are elected by the Membership at this meeting. He read the following report:

President (to serve one year)	Charles S. Redding
Vice-Presidents (to serve one year)	Walton Forstall
	W. Chattin Wetherill
	S. S. Fels
	Richard W. Lloyd
	Richard T. Nalle
Treasurer (to serve one year)	Morton M. Price
Managers (to serve three years)	Irenee duPont
	Rupen Eksergian
	W. H. Fulweiler
	Horace P. Liversidge
	Malcolm Lloyd, Jr.
	Marshall S. Morgan
	Edward Warwick
	D. Robert Yarnall

Respectfully submitted,

GEORGE S. CRAMPTON,
JAMES D. LEE, JR.
J. LOGAN FITTS,
Tellers.

The Secretary then pronounced the gentlemen named as duly elected to their respective offices for the times indicated.

The President expressed his appreciation to the Tellers for their services to the Institute.

He also thanked the membership for their vote of confidence in returning him to office and expressed the same sentiments on behalf of the other Officers and Board of Managers elected.

Mr. Redding stated that at this meeting it was customary to read the report of the Board of Managers made annually through the President. He asked permission however to read only excerpts inasmuch as the report in full would be published in the JOURNAL of the Institute. (The Report in full follows these Minutes.)

The President then introduced the speaker of the evening, Major General G. M. Barnes, who spoke on "Our Weapons". He discussed ordnance weapons developed and used in World War II and evaluated each type. The lecture was illustrated by views showing the weapons used in the various war zones. The paper will be published.

At the end of the lecture, General Barnes kindly consented to answer questions. After some discussion the meeting was dismissed with a rising vote of thanks for a very interesting and instructive meeting.

HENRY BUTLER ALLEN, *Secretary.*

REPORT OF THE PRESIDENT TO THE BOARD OF MANAGERS OF THE FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA, COVERING THE OPERATIONS OF THE INSTITUTE FOR THE YEAR 1945.

The Annual Meeting of The Franklin Institute is the time appointed in the By-Laws when the Board of Managers, through the President, shall make a report on the year's activities. The following report, prepared by the President, was duly approved by the Board of Managers, and the President was instructed to present it to the membership of the Institute this evening as the report of that body.

This is a brief summary of the activities of The Franklin Institute, together with a statement of its financial status, for the year 1945.

The year opened with our country still at war on all fronts. It ended with the wars successfully concluded and with our country busy on reconversion problems. We of the Institute can be proud of the contributions of the Institute to the war effort.

That the war work done at the Institute was successful is attested by the presentation of the Distinguished Service Award by the Ordnance Department of the United States Army, as reported last year, and by the presentation of an Award by the Bureau of Ordnance of the Navy Department which is made a matter of record later in this report. The work for both Army and Navy, carried on partly through the National Defense Research Committee and partly direct, was largely continued through the entire year and, in fact, is still going on.

The property of the Institute is entered on the books at $5,779,500. Of this amount, real property (building and equipment, not including those exhibits which have been donated) amounts to $4,125,400, and personal property (securities and cash) amounts to $1,654,200.

At the end of 1945, the Institute's investments in securities at book value were:

Largely available as to income only	$ 646,400
Available unrestrictedly	914,400
	$1,560,800

The following figures, covering income and expense, represent a close estimate of the financial operation of the Institute for the year. Final figures will not be available until the closing of the books some weeks hence.

Income	*1945*
From:	
Dues	$ 57,000
Admissions	48,800
Investments	60,400
Other sources	806,300*
Friends of Franklin	25,400
Total	$997,900

Expenses	*1945*
General	$215,600
Museum Operation	123,400
Library	18,500
Publications	18,000
Meetings	2,200
National Franklin Committee	3,500
Other	577,600†
Total	$958,500
Gain for the year	$ 39,400

* $708,000 of this item represents work done for and space provided to Government Departments in connection with war work.

† All but $6,500 of this item covers direct outlay in connection with Government work.

As to this year's gain of $39,400, I again call your attention to the fact that the gain, as in the two previous years, is entirely due to the large amount of Government work done at the Institute during the year. Our compensation for this work included, in addition to direct charges covering labor and material, a reasonable portion of our overhead expense (all of which is normally borne by the Institute) applying to the space and facilities devoted to the Government work. Now that the war is over we have formulated and are putting into operation a plan which we believe will serve eventually to eliminate the annual deficit which troubled us so much before the war years. This plan will be discussed later in this report.

Again we express to the fine group constituting FRIENDS OF FRANKLIN our gratitude for their continuing generosity. The contributions from this group have exceeded those for the previous years. Again, we bespeak the continuing support of this group until we have successfully completed the reconversion job we have ahead and have the Institute on a firm self-supporting basis.

The Membership Committee reports that our membership has suffered some losses by deaths and resignations, but 1289 new members were elected for the year, making a total of 5,449 members for all types of membership. The Committee and staff are unceasing in their efforts to place the advantages of the Institute before prospective members and have earned our thanks for their good work.

As of the end of the year, the Institute had 249 persons on its payroll. The maximum number during the year was 322. The 249 employees at the end of the year included about 95 who are still engaged in research and development work for the government.

The attendance, both free and paid, at the Museum and Planetarium, for the year under review and the previous year, is shown in the following table:

	Museum		*Planetarium*		*Total*	
	1945	*1944*	*1945*	*1944*	*1945*	*1944*
Paid	143,317	123,964	71,941	74,063	215,258	198,027
Free	55,478	45,631	38,882	35,728	94,360	81,359
Total	198,795	169,595	110,823	109,791	309,618	279,386

The drop in attendance in the Planetarium is giving us some concern and plans are under way leading to an increased interest in that important part of our Museum activities.

The year in the Museum and Planetarium has begun the process of reconversion from war to peace, though only a beginning has been made. The slackening of pressure and reduction of hours of our staff assigned to the research work has permitted a start on our backlog of deferred exhibit and building maintenance and allowed a small surplus of effort toward planning new exhibits. The increasing availability of materials is gradually putting more and more exhibits back in working order. Our Museum attendance was greatly helped by The Atlantic Refining Company's Driverater, which opened June twenty-fifth, and by the Naval Aviation Training Exhibit, which from July ninth occupied one and a half exhibit rooms and also a balcony. The efficient and cheerful naval personnel attached to it gave our visitors very excellent service.

To stimulate the interest of the youth of Philadelphia in aviation, the Institute inaugurated monthly contests, sponsored by the Standard Oil Company of Pennsylvania, based upon the use of the Link Trainer in the Hall of Aviation. Flights above the City and silver wings were offered as awards to the winners.

Dr. Marshall became Director of the Fels Planetarium January 15, 1945. An expedition, headed by Dr. Marshall and sponsored by the Philadelphia Evening Bulletin, went to Saskatchewan to observe the total solar eclipse of July 9th. This resulted in favorable publicity not only throughout the United States and Canada but overseas as well.

The Institute also collaborated with the Bulletin in presenting a "Victory Exhibit" in Franklin Hall, showing models and items made by prisoners of war, and a fine collection of paintings.

Three of our former staff have returned from service with the armed forces, but we must fill a number of other vacancies before the Museum and Planetarium are running smoothly.

During the year there was an increase in the use of the Institute by schools, as the following table will show:

	1944	*1945*	*Per Cent of Increase*
Paid	27,225	38,868	43%
Free	33,633	42,675	27%
Total	60,858	81,543	35%

Work with teachers was stressed and conferences held with educators to increase the use of the Institute for school work.

Faculty meetings were held in the Museum, when teachers were shown the most effective use of the Museum as a teaching aid. Students in State Teachers Colleges and educational schools of nearby universities have made many visits.

Lectures have been given to groups of educators of the Philadelphia area. A series of lectures designed to help teachers use Museum techniques was presented with the Academy of Natural Sciences as co-sponsor after consultation with the Curriculum Office of the Board of Education.

The 19th annual series of Christmas Week Lectures for Young People under the James Mapes Dodge Foundation was given by Faber Birren of New York, nationally known authority on color. He spoke on "The World of Color".

The two radio programs, "Science is Fun" and "Great Moments in Science," continued. For both programs Teachers' Manuals have been prepared and distributed to schools in the listening area.

Dr. William L. Fisher joined the Department as an assistant. The teacher assigned by the Board of Education continued excellent work in connection with the Philadelphia public schools.

Despite the continued wartime curtailment of Museum activities, The Franklin Institute remained very much in the news during 1945. The marked increase in newspaper, radio, and magazine coverage of Institute activities was especially noteworthy in connection with Medal Day.

Another and far more important news event, the atomic bomb, enabled the Institute to serve the public as a ready source of accurate information. Comments and explanations from staff members were picked up by news services and widely reprinted.

Publicity for companies sponsoring industrial and photographic exhibits was carried out in cooperation with the individual industries.

Our Industrial Cooperation program now has been in effect for over five years. The total receipts during 1945 amounted to $24,000, representing contributions received from ninety-eight companies. There have been very definite major changes made in the following companies' exhibits during the year which have helped keep alive and stimulate visitor-interest: E. G. Budd Manufacturing Company; Sun Oil Company; Standard Oil Company and Warner & Swasey; Westinghouse; Davison Chemical Corporation; Champion Paper and Fibre Company.

Our Librarian reports continued interest by members and the public in the use of the outstanding advantages offered by the Institute's Library. In 1945 the attendance was 8,474, with 6,219 phone calls for additional information. Photostat orders brought requests for 13,800 prints.

The following additions were made to our collections during the year:

New Books—Purchased	431
New Books—Gifts	340
Pamphlets	1,040

The total contents of the Library as of December 31, 1945, were:

Volumes	129,666
Pamphlets	45,406
Maps	4,122

Mr. George E. Pettengill joined the Library staff in March as Assistant Librarian.

The members of the Committee on Science and The Arts have continued to maintain the high standards set in previous years. The entire Committee met eight times, while forty-one sub-committee meetings were held. Eight Medals and two Certificates of Merit were awarded at the annual Medal Day exercises. The Franklin Medal was awarded to Dr. Harlow Shapley.

It is of interest to note that four members of the Science and Arts Committee were with the armed services: one as a Colonel in the Army, and one Captain and two Commanders in the Navy.

Immediately after the cessation of hostilities in the European theater, a letter was received from a former medalist in France, stating that the Nazis had taken his gold medal. He asked to purchase a duplicate. Another letter from the widow of a Franklin medalist in England stated that her husband had sold his gold awards to aid the Government and asked for a reproduction to complete his collection for exhibition purposes. In both cases the Institute was delighted to furnish the medals without cost to the recipients.

Twelve numbers of the JOURNAL were issued during the year. Articles for the JOURNAL are becoming increasingly available and there is no indication that there is any likelihood of the JOURNAL losing its high place in the field of technical literature.

Our two research laboratories, the Bartol and Biochemical, continued their activities on war work during the first months of the past year.

Since the termination of the war, the Bartol Research Foundation has been asked by the Government to continue, at any rate for a time, certain of the researches which have been under way and which have been attended with considerable success. The Foundation has been making a slow transition towards peacetime activities, and as part of this program, and through the efforts of Dr. Lyman J. Briggs, former director of the Bureau of Standards (and a member of the Bartol Committee), and of General Arnold, a plan has been made to conduct, for the cosmic ray measurement program, a series of flights in B-29 bombers between this latitude and the equator. This project is also being directly sponsored, and to some extent financially supported, by the National Geographic Society.

The Biochemical Research Foundation is still working for the Manhattan District on

atomic energy problems and will continue to do so until next June. Secrecy, however, is expected to be lifted in regard to the medical aspects. The laboratories have been doing considerable experimental work on aspects of radio-activity and have quite a full program outside of the work of the Manhattan District.

The National Franklin Committee continues its work of making Franklin better known by distributing thousands of pieces of material throughout the country to schools and organizations requesting it. The demand has become so great that the articles are now in printed pamplet form, for better reading and distribution.

That this activity is bearing fruit is evident from the fact that General G. C. Marshall, Chief of Staff, United States Army, recently commented to us that he ". . . never will cease to enjoy or profit by exposure to Dr. Franklin's wisdom." And from Pittsburgh, Pennsylvania, a donation was received from a group explaining that the money had been collected to do honor to Franklin; that they had not been able to complete their project and were therefore turning the money over to the Institute to be used in promoting Franklin interests.

The Hostess Committee and its Executive Board have been responsible for some outstanding social events held in connection with Institute functions. The Committee assumed responsibility for the reception to medalists and other guests preceding the Medal Day dinner and awards; and in July the Executive Board gave a reception for distinguished naval officials attending the opening of the Naval Aviation Training Exhibit. In October Mrs. John White Geary was re-elected Chairman; Mrs. Isaac A. Pennypacker, Vice-Chairman, to succeed Mrs. Livingston E. Jones. Throughout the year usual meetings and luncheons were held, and the routine care of restrooms continued. We are all deeply grateful to the Hostess Committee for its social and financial assistance, which continues to play such an important part in the affairs of the Institute.

A fine tribute to The Franklin Institute for its war work was received in December when the Bureau of Ordnance, U. S. Navy Department, presented its Naval Ordnance Development Award, "conferred for distinguished service to the research and development of naval ordnance, and in particular for outstanding contribution to the development of Pilots' Universal Sighting System." The device mentioned is one on which details may not yet be revealed. The congratulations of the Bureau of Ordnance were extended to every man and woman of the Aircraft Fire Control Research Group under the direction of Mr. Ralph H. McClarren for outstanding performance in connection with the research and development of aircraft fire control instruments and associated equipment. Admiral G. F. Hussey, Jr., Chief of the Bureau of Ordnance, Navy Department, came from Washington to deliver the citation in person in the Hall of the Institute. At the same time nine individuals of the Institute's staff were signalled out for honors, while the entire group of persons who worked on the project were greeted by Admiral Hussey and presented with a Navy Ordnance lapel button.

During the year, the Board lost through resignation one member, Dr. George P. Rea, who has removed to the Pacific Coast. The vacancy created by Dr. Rea's resignation has not yet been filled.

I have left to the end of this report any definite statements as to the future. As has been indicated in previous reports and touched upon earlier in this report, the Board has been under the weight of the deficits of the prewar years and has been fully conscious that something would have to be done to insure future operations with a balanced budget. A most likely solution to this problem became more and more evident during the war years. That solution lies in continuing research and development work at the Institute for both Government departments and industry upon such a financial basis as will enable the Institute to be self-supporting. A committee of the Board, under the able leadership of Dr. Clamer, has been studying this problem for some time and we are now prepared to proceed. An able man has been engaged to head up this activity, under Dr. Allen, and we confidently look forward to its eventual success. Factors of space and equipment will perhaps prevent a rapid growth of this venture, but these can be overcome. That the Institute should follow this course is quite in line with its history and traditions and we are sure that its standing will be enhanced by this activity.

In connection with our research and development program, I am happy to record a gift of $10,000 from Mrs. David Halstead for equipment for our research and development laboratories in memory of her husband who for many years was much interested in the affairs of the Institute. Details of this gift were published in the Institute News of November, 1945.

And, finally, may I again express to the other officers of the Institute, the members of the Board of Managers, and the Institute's staff, under the able leadership of Dr. Allen, my thanks for and appreciation of the friendly and helpful cooperation which I have enjoyed during the year.

CHARLES S. REDDING,
President.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, January 9, 1946.)

HALL OF THE COMMITTEE,
PHILADELPHIA, JANUARY 9, 1946.

MR. JAMES D. LEE, JR., *in the Chair.*

The following reports were presented for final action:

No. 3150: De-Icing of Airplane Wings,

This report recommended the award of a John Price Wetherill Medal to John A. Rodert, of Moffett Field, California, "In consideration of his important and applied work in developing a thermal ice prevention system for airplanes."

No. 3162: Brown Medal.

This report recommended the award of the Frank P. Brown Medal to Charles Terzaghi, of Cambridge, Massachusetts, "In consideration of his theoretical and technical knowledge, initiative, pioneering research and outstanding leadership in the establishment of the Science of Soil Mechanics."

JOHN FRAZER,
Secretary to Committee.

LIBRARY NOTES.

The Committee on Library desires to add to the collections any technical works that members would wish to contribute. Contributions will be gratefully acknowledged and placed in the library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print 9×14 inches is thirty-five cents.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesdays and Thursdays from two until ten o'clock P.M.

RECENT ADDITIONS.

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HARRIS, ROBERT S., AND KENNETH V. THIMANN. Vitamins and Hormones. Volume 3. 1945.

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FRANKLIN, BENJAMIN. A Benjamin Franklin Reader. Edited by Nathan G. Goodman. 1945.

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DEGERING, ED. F., AND OTHERS. An outline of Organic Nitrogen Compounds. 1945.

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BRAY, A. Russian-English Scientific-Technical Dictionary. 1945.

ELECTRIC ENGINEERING.

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HAGER, DORSEY. Fundamentals of the Petroleum Industry. First Edition. 1939.

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BELL, E. T. The Development of Mathematics. Second Edition. 1945.

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TOWN, H. C., AND D. POTTER. Cutting Tool Practice. 1945.

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MAWHINNEY, M. H. The Heating of Steel. 1945.

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BERRY, F. A., E. BOLLAY, AND NORMAN R. BEERS. Handbook of Meteorology. First Edition. 1945.

STEWART, JOHN Q. Coasts, Waves and Weather for Navigators. 1945.

MINEROLOGY.

American Mineralogist. Symposium on Quartz Oscillator-Plates. 1945.

PHOTOGRAPHY.

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U. S. Camera 1946.

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HAWLEY, GESSNER G., AND SIGMUND W. LEIFSON. Atomic Energy in War and Peace. 1945.
MAURER, EDWARD R., RAYMOND J. ROARK AND GEORGE W. WASHA. Mechanics for Engineers. 1945.
PICKARD, R. FORTESCUE. Time, Number and the Atom. 1945.
YARWOOD, J. High Vacuum Technique. Second Edition. 1945.

RAILROADS.

BEEBE, LUCIUS. Highball: a Pageant of Trains. 1945.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

Nature of the Inhibition of Ribonucleinase and Succinic Dehydrogenase by Mononucleotides.—CHARLES A. ZITTLE. Previous studies have shown that ribonucleinase (1) and succinic dehydrogenase (2) are inhibited by mononucleotides from ribonucleic acid. In the case of the former it was presumed that the inhibition was due to competition with the substrate since mononucleotides are formed by the action of ribonucleinase on ribonucleic acid. The curves relating percentage inhibition and concentration of inhibiting substance were hyperbola, and although indicative of a dissociable reaction between enzyme and inhibitor, do not throw any light on the nature of the effect. The few experiments performed with different concentrations of substrate showed very little variation in the degree of inhibition; these experiments have been extended and since the inhibition is independent of the concentration of the substrate, it must be concluded that the inhibition is not competitive (3, 4).

Experiments with succinic dehydrogenase in which the concentration of the substrate was varied showed that here too the degree of inhibition changed very little. The data of Adler *et al* (5) for the effect of adenosine on succinic dehydrogenase with variable concentrations of substrate were similar.

The experimental conditions were the same as described previously (1, 2). The inhibition data are given in Tables I and II and show that within the accuracy of the measurements the inhibition is independent of the concentration of the substrate. With the two higher concentrations of the substrates, since the rates of reaction are the same, the enzymes must be saturated with the substrate.

TABLE I.

Inhibition of Ribonucleinase by Mononucleotides with Several Concentrations of the Substrate Ribonucleic Acid.

Ribonucleic Acid mg.[2]	With No Inhibitor	With 13.8 mg. Mononucleotides[1]		With 26.6 mg. Mononucleotides	
	Rate cmm./10 min.[3]	Rate cmm./10 min.	Inhibition per cent	Rate cmm./10 min.	Inhibition per cent
215	94	83	11.7	77	18.1
144	94	83	11.7	76	19.1
72	79	74	6.3	63	20.2

[1] The mononucleotides were prepared by complete hydrolysis of ribonucleic acid with NaOH (1); 10 mg. = 2.9×10^{-5} moles.

[2] In total volue of 3.5 cc. (1).

[3] CO_2 liberated with 31.2 γ ribonucleinase; corrected for retention of CO_2 (6).

TABLE II.

Inhibition of Succinic Dehydrogenase by Mononucleotides with Several Concentrations of the Substrate Succinic Acid.

Succinate, 0.5 M cc.[1]	With No Inhibitor	With 4.6 mg. Mononucleotides		With 6.9 mg. Mononucleotides	
	Rate cmm./10 min.	Rate cmm./10 min.	Inhibition per cent	Rate cmm./10 min.	Inhibition per cent
0.3	120	46	61.7	18	85.0
0.2	120	42	65.0	18	85.0
0.1	113	35	69.0	18	84.1

[1] In total volume of 3.2 cc.

Since inhibition of both of the above enzymes is non-competitive it might be accomplished by the same mechanism; this idea is supported by the observation that in both cases (1, 2) the mononucleotide yeast adenylic acid is less inhibitory than guanylic acid. Evidence which appears to be to the contrary is the difference in magnitude of the inhibition of the two enzymes and, more important, the very strong inhibition of succinic dehydrogenase by thymus nucleic acid (2), whereas in the same concentrations it has no effect on ribonucleinase. Experiments with other enzymes are contemplated to determine the extent of this inhibition.

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(4) ELVEHJEM, C. A., AND WILSON, P. W., "Respiratory Enzymes," Burgess Publishing Co., Minneapolis, 1939, p. 214.
(5) ADLER, E., VON EULER, H., AND SKARZYNSKI, B., *Ark. Kemi, Mineral. Geol.*, **17A**, No. 2, 1943.
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BOOK REVIEWS.

PRINCIPLES OF FIREARMS, by Charles E. Balleisen. 146 pages, illustrations, 14 × 22 cms. New York, John Wiley & Sons, Inc., London, Chapman & Hall, Limited, 1945. Price $2.50.

This book deals with modern types of small arms such as hand arms, shoulder arms, and machine guns. It is an attempt to fill a void in the literature of this country for an engineering analysis of the machinery of firearms. It is significant that source material available in this country to engineers who have been called upon to design weapons is either in the French or German language or exists in only very limited quantities.

The treatment starts with a brief outline of the processes of interior ballistics—those which occur within the barrel of the firearm when it is discharged, and this is immediately followed by a description of the recoil due to the reaction caused by the forward motion of the projectile and the reaction of the expanding powder gases after the bullet has emerged. With this as a background there is then given space to automatic weapons, their functions, systems, and existing types. Trigger and sear mechanisms, cartridge feeds and sights are topics subsequently taken up. There is also a chapter on unsolved problems of gun design involving items some of which are design faults and some natural results of physicochemical processes employed to operate the gun. These include bore erosion, corrosion, lubrication, climatic expansion, direct stoppages. The methods of testing weapons are undergoing considerable change, although the older methods still predominate and for this reason as well as the fact that they are satisfactory for rough or general work the older methods are described, as are also new methods. The two appendixes are devoted to exterior ballistics and gun mounts. At the end of each chapter or appendix there is a brief bibliography of books and periodicals which have a general bearing on material discussed in that chapter. There is a subject and index at the back of the book. The work is illuminating to the physicist and engineer in bringing out basic principles and the mechanics of operation of the gun.

R. H. OPPERMANN.

WILLIS RODNEY WHITNEY, Pioneer of Industrial Research, by John T. Broderick. 324 pages, 14 × 20 cms. Albany, Fort Orange Press, Inc., 1945.

It has been said in years past that the practical value of pure research was questionable. But as time went on and marvelous developments followed revealed knowledge of pure science there was less heard of such questions. They are now never heard, especially since the recent development of knowledge of the atom. The tremendous sums spent in pure science research, the work and the lives of great men spent in its pursuit all are recognized today. There is a never ending debt of gratitude to those who labored to discover new facts when their very work was questioned as to its value.

One of these men was Willis Rodney Whitney, a physical chemist, graduate of Massachusetts Institute of Technology, student in Ostwald's Laboratory at the University of Leipzig, and at the Sorbonne in Paris under Charles Friedel. After having taught school and having finally decided on an industrial career, Dr. Whitney accepted a position with the General Electric Company at the turn of the century. This offer and acceptance marked the beginning of an active and productive life for Dr. Whitney, and it was a signal that pure research had won recognition and was to have tangible support by the General Electric Company, although no one could have forseen at the time how great would be its contribution for forty years to the expansion of the electrical industry.

In the early years of the Research Laboratory, while its staff was small, Dr. Whitney was able to continue the individual researches started while he was a school teacher which held such fascination for him. It was his own experiments which led to the invention of the metalized carbon filament, the first big advance in incandescent lamp efficiency beyond the point which

Edison had reached. He developed the ceramic type of high resistance rods used with lightning arresters and contributed directly to the development of the magnetic arc electrode and of the mercury arc rectifier. By his own work he showed how so stubbornly unpromising a thing as the bit of carbon used in a commutator brush might be so improved as to better the performance of a motor on which it was used, and how, by a similar application of scientific methods, improvements could be introduced into one of the oldest and most completely standardized of arts, that of porcelain manufacture.

The growth of the Laboratory, however, became rapid and soon the demands upon his time as a director severely restricted his individual activities, although, he has always maintained a workroom next to his office. With this growth, the Research Laboratory was losing a great experimenter but was gaining a yet more valuable asset, a great research director. Whitney's name has been directly connected with only a few of the important products of the Laboratory in its more mature years, but his colleagues and assistants know how much of the credit belongs to the wise and inspiring leadership under which those products grew to fruition.

This book is an unusual type of biography, in not being elaborate. Instead, it is a narrative sufficiently restrained to be in keeping with the character of its subject and extended enough to familiarize the reader with a pioneer and leader in making physical research fascinating and fruitful. Included are records of conversation and some typical Whitney writings and addresses such as that given at the Franklin Institute. In these Dr. Whitney tells the story of his life and activities. They are interesting, instructive, inspiring and novel.

R. H. OPPERMANN.

PHYSICAL CHEMISTRY OF CELLS AND TISSUES, by Rudolf Hober and others. 676 pages, illustrations, 16 × 24 cms. Philadelphia, The Blakiston Company, 1945. Price $9.00.

The gap thought to exist between chemistry and physics is ever growing narrower. For qualities of matter spatially distributed quantities have been substituted within the past twenty years. And with this, inquiry has been directed to biological phenomena. Research workers realize the necessity of studying physiology as a branch of physical chemical science dealing with life as a physical, though exceedingly complex system, that may be subjected to scientific analysis like any other natural object. This is the background of the book at hand. Since a branch of physical chemistry deals with laws governing rates by which equilibrium is attained, and living cells and tissues are not in equilibrium, the discussion of rates must occupy a prominent place in the work.

The first two sections of the book survey the fundamentals of classical physical chemistry outlining numerous grades of structural complexity of atoms and molecules and defining the forces involved in their linkage or disrupture. Special attention is given large molecules, illustrating their behavior by describing their occurrence in the principal structural forms met with in nature: in fibers, in interfaces and membranes, in condensed masses, and in the dispersed state. With the third section the progression enters the realm of research upon living systems. Following introductory remarks about some physicochemical aspects of protoplasm as the basic substance in all living things, animals and plants, cells and tissues, there is dealt with the surface of the protoplast, its properties and its architecture, with environmental influences on manifestations of cell life, with cell metabolism and cell energetics, with excitability and contractility, with active transfer as superimposed to passive penetration.

The tool of modern physics is used to analyze and segregate the elemental processes of all life and in doing so many important facts are brought to light. There are developments in the field of submicroscopic structures. There is offered the approach to the problem as to how, in cell life, chemical energy is transformed into mechanical or osmotic work. The trend of progressing is logical and interesting. Many references are made to previous work which is digested and built upon in additional research. Interpretations are made and there is clearly indicated the limits of present definite knowledge.

The book is an original recording of extensive studies to the very threshhold of the unknown. It is a guide to new researches.

R. H. OPPERMANN.

A BENJAMIN FRANKLIN READER, edited by Nathan G. Goodman, 818 pages, 15 × 22 cms. New York, Thomas Y. Crowell, 1945. Price $3.50.

"A Benjamin Franklin Reader" is a plesaant title and self-explanatory. Mr. Goodman has given us an admirable sampling of the work of Dr. Franklin, and has made selections which should have a wide appeal.

It is an excellent book to serve as an introduction to a great American who even today enters daily into our lives with his unfailing common sense and practical approach to all subjects.

The author has divided his selections in a manner calculated to catch the interest and arouse the curiosity of the reader. Many will be surprised to note the space given to Franklin's "Religious Beliefs," and will find inspiration in them. In our own troubled times it should prove comforting to know that Benjamin Franklin, statesman, diplomat, scientist, businessman—the outstanding figure of another struggling era—, was guided by his beliefs in and dependence upon God.

But Mr. Goodman has also portrayed for us, by his skilful digest, Franklin as an "Editor and Publisher"; "Promotor of the General Welfare"; "Practical Scientist"; and the "Family Circle." Other chapters of carefully chosen works give Franklin's diplomatic career. The inclusion of the "Autobiography" and several humorous pieces, some not so well-known, is bound to make the book a great favorite.

It would seem he has divided his researches to meet the needs of the busy man, who needs a ready reference, as well as for the student who will be enticed to delve further into the writings of this man who wielded such a vast influence. A real contribution on the part of the author is the section on the "Practical Scientist." It brings together all of Franklin's discoveries, inventions, and observations. Here again the reader who has but a casual acquaintance with Benjamin Franklin will be surprised to learn that he owes so much of his own well being to this ingenious man.

It is a bit disconcerting to find, however, the letter to Jared Elliott regarding the so-called "Franklin Experimental Farm" in New Jersey. In 1940 Dr. C. R. Woodward, who has devoted many years to the study of Franklin and his agricultural pursuits, made public his findings that the letter was not written by Franklin. His proof was conclusive enough to cause the Yale University Library to remove the letter from its collection. ("Meet Dr. Franklin," p. 184). If Mr. Goodman does not agree with these findings, a note of explanation of his own theory would have proved helpful.

Another statement in connection with Franklin's legacies to the City of Boston is very misleading. Mr. Goodman states that part of Franklin's legacy to Philadelphia was given to The Franklin Institute, in accordance with stipulations, and that "In Boston, under the terms of the will, 4,767 Franklin medals have been awarded to students of the high schools . . . ." This is true, but the medals are purchased from the sum Franklin left for that purpose as mentioned in the body of his will, and not from the Fund identical to the one given to the City of Philadelphia and mentioned in the codicil of the will. *That* money was used by the City of Boston to found the Franklin Union, now known as the Franklin Technical Institute. And under "Condolences" I do wish the author had included Dr. Franklin's letter to Miss Hubbard. It's very consoling!

"A Benjamin Franklin Reader" is a lovely book in appearance—good paper, clear, readable type, with many illustrations showing Franklin's inventions or diagrams of them, and intriguing little sketches to recall how Franklin lived. A book worth possessing.

ELIZABETH D. CONNELLY.

PUBLICATIONS RECEIVED.

A Collection of Papers in Memory of Sir William Rowan Hamilton. The Scripta Mathematica Studies, Number Two. 82 pages, 17 × 25 cms. New York, Scripta Mathematica, 1945. Price $1.50.

Sequential Analysis of Statistical Data: Applications. 6 sections, 26 × 29 cms. New York, Columbia University Press, 1945. Price $6.25.

The Heating of Steel, by M. H. Mawhinney. 265 pages, drawings, tables and illustrations, 15 × 23 cms. New York, Reinhold Publishing Corporation, 1945. Price $4.75.

Inside the Vacuum Tube, by John F. Rider. 407 pages, drawings, tables and illustrations, 14 × 22 cms. New York, John F. Rider Publisher, Inc., 1945. Price $4.50.

Science and Scientists in the Netherlands Indies, Edited by Pieter Honig and Frans Verdoorn. 491 pages, 18 × 27 cms., illustrations. New York, Board for the Netherlands Indies, 1945. Price $4.00.

Electron Optics and the Electron Microscope, by V. K. Zworykin, G. A. Morton, E. G. Ramberg, J. Hillier, and A. W. Vance. 766 pages, drawings and illustrations, 14 × 22 cms. New York; John Wiley & Sons, Inc.; London: Chapman & Hall, Limited, 1945. Price $10.00.

CURRENT TOPICS.

The Hopes of Post War Light Sources.—Samuel G. Hibben, Director of Applied Lighting for Westinghouse Electric Corporation, has recently stated that in the research laboratories of Westinghouse there are among many of the problems receiving constant attention the very vital ones of transferring electrical energy directly to radiant energy without the intermediate step of heat. The objective is old, but several recent approaches are new. When this war began, some 95 per cent. of the man-made light sources were tungsten filament lamps having their optimum economic light emission when the filaments were operated at a temperature of approximately 3000° K., and whereof the heat losses were on the order of 90 per cent. of the input energy. This did not seem good enough.

The commercial Mazda filament lamp with its efficiency of some 14 lumens per watt, where 7.5 per cent. of the input energy is converted into radiation to which the human retina responds, may well remain a standard article for household use and for small wattage local industrial lighting equipment but the urge for interior large-scale lighting and for illumination levels on the order of 50 to 100 footcandles demands that higher efficiencies be attained. How high are our hopes?

Romantically, the scientist turns again to studies of the firefly, of luminescent bacteria, and of chemiluminescence or bioluminescence in Nature. It is roughly estimated that 90 per cent. of the radiant emission from a firefly is luminous, closely approaching 500 lumens per watt. This is ten times the ultimate efficiency that could be expected from a tungsten filament lamp since tungsten when melting at about 3655° K. could generate visible light at no better than 55 lumens per watt. If such a lamp were to burn for several hours, an efficiency of 35 lumens per watt would more correctly represent a practical top limit.

Like the firefly, most of Nature's lamps produce light by oxidation. No energy whatever is wasted in the production of invisible ultraviolet light and practically none in heat radiations. Man's latest lamps willy nilly generate much of both.

It appears that Nature's illuminants developed simultaneously with Nature's seeing organs. The luminous emission from a typical insect like the firefly is confined to a very narrow band of wave lengths, concentrated at the central point of the visible spectrum or at the light yellow-green color region (5700 A) where the response of the retinal nerves is most sensitive. Little or nothing is lost in emitting red or blue colors. By contrast, man's illuminants, particularly those of the hot body or incandescent types, emit a great deal of light at the long wave and also the short wave ends of the visible spectrum and it is this radiation which, in addition to the infra-red and ultraviolet, is generally wasted so far as seeing is concerned.

From a study of the color response characteristics of the human retina we might conclude that the sodium vapor lamp for instance which concentrates practically all of its luminous output at a wave length of 5890 A (lemon yellow)

would be the best light source for general purpose seeing. However, a study of this and other almost monochromatic lamps indicates one further difference between Nature's illuminants and man's. The purpose of the latter is to make surrounding objects visible by light reflection therefrom, whereas Nature's lamps are primarily to be seen as signals, or markers, or lures. Man's seeing judgment depends to a large extent upon the color of the object being viewed and hence a monochromatic source with its resultant distortion of object color fails to meet our broad criteria for the ideal illuminant of tomorrow.

When we employ the energy of electricity to displace or excite the outermost electrons of the mercury atom within the commercial tubular fluorescent lamp, thereby generating short wave ultraviolet radiations, and when this radiation in turn upsets the normal atomic arrangement of the phosphor crystals coated on the inside of the glass tube, we have achieved a "short-circuiting" light making process—i.e., we eliminate the production of much heat. By this method some 18 to 20 per cent. of the input energy is converted to usable light. This still seems not good enough.

An arc discharge through high pressure mercury vapor ranging from 1 to perhaps 80 atmospheres (but commercially at about 3 to 5) develops luminous radiation at a commercial efficiency on the order of 65 lumens per watt. This is better—and further research will increase this efficiency in proportion as we can increase the temperature and pressure of the mercury vapor. The problem here is the refractory characteristic of the container. Summing up the situation we then have this analysis:

1. Tungsten filament illuminants now developing some 15 lumens per watt and practically limited to 35 or to a theoretical and ultimate maximum 55.
2. The fluorescent lamp, now developing some 45 to 60 lumens per watt and capable of doing roughly twice as well, as the technique of developing 2537 A ultraviolet from mercury vapor and of efficiently exciting phosphor crystals therewith is perfected.
3. High pressure metallic vapor discharge lamps now producing 55 to 70 lumens per watt and theoretically capable of going considerably higher in efficiency if refractory containers could be had so as to permit increases in temperature that accompany pressure beyond roughly 5 atmospheres.

These, then, are some of the present day problems in lighting research that seem to offer a challenge to the engineer who recognizes that post-war lighting requirements will demand vastly more artificial illumination than man has heretofore enjoyed.

R. H. O.

Electrocoating Fabrics.—The old high school physics trick of rubbing a glass rod with a piece of silk thereby attracting bits of paper to the rod has given birth to a new business—that of electrocoating fabrics—and in postwar years the design on milady's dress, the upholstering on a chair, and even the nap of a rug on the floor may have been electrocoated rather than woven.

The principle behind the old trick—that of creating static electricity—has been known to mankind for 2,500 years, but it was not until a few years ago that Behr-Manning Corporation of Troy, N. Y., with the aid of General Electric equipment, began to apply it in making coated abrasives or sandpapers.

Then followed the question: Why not fabrics? Experimentation with successful results ensued, but the war intervened, and the new wrinkle, as far as large scale production is concerned, was tabled for the duration.

Electrocoating fabrics, or the rod and silk trick "grown up," is a process whereby cloth fibers sent through an electrostatic field become charged, stand on end, and are hurled perpendicularly against an adhesive-coated "backing" fabric. The result is creation of either a new fabric or a design on the original fabric.

The electrostatic field is set up by General Electric high voltage electrical equipment. Loose fibers, or flock, when conveyed on a belt through the electrostatic field, receive a charge of the same polarity as an electrode at the bottom of the field.

Because of the similar polarity, the fibers are repelled upwards with such force that they are hurled perpendicularly into an adhesive-coated "backing" fabric, which is being run simultaneously through the field. Ends of the fibers are buried in the adhesive of the fabric. Final step is conveying the resultant electrocoated fabric through a dryer for "curing."

In making designed goods, the pattern is printed with adhesive on the "backing" fabric. When run through the electrostatic field, the fibers cling only where the adhesive design appears. In final form, fibers resemble fine embroidery.

Through the electrostatic process, fibers will cling to any kind of adhesive-coated "backing," even paper of the quality of rough newsprint. An entirely synthetic fabric can be created by impelling synthetic fibers upon a sheet of cellophane. As novel as it may seem, the resultant fabric is a tough, densely napped cloth that might be used as a table runner.

Extremely short fibers can be impelled against leather or leather facsimile so as to create a new kind of suede shoe leather. In like manner, "velvet" lining, for anything from a jewelry box to a casket, can be made. A recently conceived application is that of upholstering metal turntables on phonographs. Tests have proved that greater density of electrocoated fabric provides better acoustics for a record player.

Through the electrostatic process, a fur coat could be made in such a way that the fur would be much more densely napped than that of a hide and in such a way that the wearer need never fear the hair falling out.

The full field of application is virtually unexplored as yet, according to Behr-Manning engineers. Applications now conceived for postwar production however include women's dresses and blouses, scarfs, neckties, overcoats, window drapes, curtains, bedspreads, bath mats, hosiery, hats, upholstering for furniture, automobiles and airplanes, and rugs and carpeting.

According to the maxim that stamina of any fabric is approximately proportional to its density, the durability of electrocoated fabrics will surpass that of woven goods. Electrocoated fibers in one square inch of fabric number as high as 300,000, which amounts to ten times the density of fibers in woven goods. Each electrocoated fiber, moreover, is exactly perpendicular to its base, affording a greater resiliency and uniformity in appearance.

Comparison durability tests on standard textile testing machines show ratios of three to one in favor of electrocoated fabrics.

R. H. O.

Wood Research.—"Develop a waterproof finish for a Navy float light to stand up as long as possible in the tropics" was the wood research problem posed the Timber Engineering Company Laboratory, Washington, D. C., by the Kilgore Manufacturing Company.

Float lights are flare signals dropped by planes to mark the position of ditched fliers or other objects in the ocean. They had been supplied to the Navy unfinished and it was found that in the humid tropics the cases absorbed moisture from the atmosphere to an extent that the powder charges were damaged. The conditions to be met were a temperature of 140° Fahrenheit and relative humidity of 95 to 97 per cent.

The laboratory developed a finish that, when subjected to a temperature of 150° Fahrenheit and a relative humidity of 95 per cent., the moisture excluding efficiency was more than 90 per cent. for a period of 14 days.

Thus was solved one of the many, diverse problems presented to the technicians at the laboratory, whose work is dedicated to increasing the efficiency and usefulness of wood. Recent distribution of a brochure, *The Forest Industries Blaze New Trails*, inspired inquiries about wood research projects from 160 manufacturers in the most varied fields.

The greatest number of inquiries came from the furniture industry, but others represented included manufacturers of window screens, venetian blinds, toys, interior woodwork, shoe heels, ten pins, handles, tanks, brushes, store fixtures, pencils, containers, sinks, stirrups, musical instruments, plastics, bobbins, chemicals, buttons, barrels, implements, ladders, wallpaper, bolts, etc. The railroad and coal industries were also represented as was the government.

Typical of the work of the laboratory is a job undertaken for the Wallpaper Institute. The problem was to develop a new type of wood roller for printing wallpaper. Prior to the war, the wallpaper industry used large numbers of hardwood rollers, approximately eight inches in diameter by 30 inches long, produced from solid billets. It was necessary to dry the billets for four years before they could be turned. During the war, stocks were exhausted and the industry could not very well wait four years to season a new supply by the old method, so it turned to the Timber Engineering Company for help. The laboratory developed a laminated product that can be turned out quickly and is more satisfactory in all respects than the solid wood rollers.

Two promising methods have been developed to produce "cigaret-proof" desk and table tops for the Wood Office Furniture Institute. One is a modified improvement of an old method wherein aluminum is employed to conduct the heat from the wood before it can damage the finish. The second depends upon a heat conducting finish wherein aluminum is not used.

At the same time the laboratory is seeking on behalf of the Institute, a chemical treatment that will permit sharper bending of wood in the manufacture of chairs, prevent spring back, and minimize breakage. Furniture has been produced from impregnated wood that is harder and more resistive to wear than the standard product.

A pilot plant at the laboratory has successfully developed a process whereby pulp can be produced economically from relatively small quantities of hardwood waste (five to 20 tons per day) with a relatively small outfit of equipment. The purpose of these experiments is to turn to account veneer clippings, edgings

and slabs from hardwood lumber, and waste from flooring and other wood products plants, as well as forest waste such as tops and limbs. The pulp thus produced has been successfully used in making liners for soldiers' helmets, containers, and felt for print linoleums. Funds have been made available by a group of six hardwood producers to establish a larger pilot plant to determine the economics of the process.

Lignin has been used in a process, developed for the U. S. Treasury, for recovering silver from waste photographic liquors. The lignin is converted into a solution that absorbs silver. It is then collected as a precipitate which is dried and the lignin burned away in an oven, leaving silver nitrate which can be used again or converted into pure silver.

The same end can be accomplished by an electrolytic process which is economical where there are large quantities of waste, but it is too expensive for use on small quantities. Preliminary surveys show that from various small, photographic laboratories in Washington alone $20,000 to $30,000 worth of silver goes into the sewers annually.

R. H. O.

German Scientists Made Startling Advances in War Research.—Because of startling advances in many fields by German scientists, the European war might still be raging had the Nazis been able to hold out for an additional few months. This appraisal of German scientific and engineering advances was made by Dr. Charles F. Green, consulting engineer of the General Electric Company, who recently returned from Germany where he served on an Army Air Forces technical mission.

Research in German laboratories, and the use of that knowledge in making armaments, were coming ahead so fast at the end of the war that the Allies' margin of superiority was rapidly decreasing, Dr. Green said.

Extensive research was being conducted by German scientists on infra-red detection. It was used to great effect, in tank warfare at night, when opposing tank units had difficulty spotting one another and closing in for the kill, he explained. The Germans developed infra-red filters for their searchlights and shot them toward areas where they believed Allied tanks were lurking. Since infra-red rays are invisible, the Allied tankmen did not know they were being illuminated.

The infra-red rays from the filtered searchlight beams hit the Allied tanks, bounced back to devices known as "bildwandlers," or "image changers," mounted on German tank guns. The bildwandlers transformed the infra-red rays into an image of the opposing tank, and the gunners opened fire.

Dr. Green pointed, however, to at least two decided superiorities held by the U. S. There was nothing in Germany to compare with the B-29 and its central fire-control system, which enabled a single gunner at a single sight to fire as many as three turrets simultaneously. Engineers of the G-E Aeronautics and Marine Engineering Division, for which Dr. Green is consulting engineer, performed all of the engineering work on the gunnery system and trained B-29 maintenance experts at G-E schools here.

There was also nothing to compare with an uncanny radar machine used by U. S. anti-aircraft units. Batteries equipped with this G-E engineered radar were in England preparing for D-day when Germany launched its do-or-

die V-1 attacks. Rushed to defense poisitions on Britain's southeast coast, the American units were a major factor in saving London from the V-bombs.

The units also made a brilliant record in Italy, France, and Germany. In the first few days of the invasion of France they got off to a flying start by downing more than 60 German planes which were visible only to the radar.

German aircraft designs were coming ahead at a fast pace, said Dr. Green. An error of major proportions was made, however, in emphasizing the Messerschmitt 163, equipped with rocket engines, instead of the Messerschmitt 262, a jet-propelled fighter which the G-E engineer described as "a phenomenal airplane."

Visiting the antiaircraft defenses of such vital industrial centers as Schweinfurt, Merseburg, and Hamburg, Dr. Green found that the Germans had used massed concentrations of AA guns in a vain effort to halt the Allied air offensive. Merseburg, near which the gigantic Leuna synthetic oil plant and a Buna works were located, alone employed more than 480 guns, even more than Berlin itself. A captured German general explained that lack of efficient remote-control electric equipment to operate the guns and fire-control instruments alone prevented the batteries from doubling their kills of Allied bombers. Such equipment, however, was standard in American units.

R. H. O.

All Electronic Penicillin Drying System.—This system speeds production and reduces costs of the drug penicillin. A single installation of the electronic system, as now perfected, can produce ready-to-use vials of penicillin at the rate of 2,000 an hour, with each vial containing 100,000 Oxford units of the renowned drug. Hourly production is sufficient to treat 400 patients requiring 500,000 units each. It is possible to operate the system as much as 20 hours a day for a total of 4,000,000,000 Oxford units.

Output at this rate exceeds that of conventional equipment occupying four times the floor space and costing triple the amount of the electronic system.

The system, which was developed by Dr. George H. Brown and his associates, C. N. Hoyler and R. A. Bierwirth, of RCA Laboratories, consists of three separate units:

1. Radio heat bulk-reducer—which completes in 30 minutes a bulk-dehydrating operation requiring 24 hours by existing method.
2. Electronic vacuum drier—which in three minutes reduces 1 cc. quantities of concentrated penicillin solution to a dry film in vials.
3. Vacuum heating chambers—which remove the last percentage of moisture from the vials, completing the drying process.

Since ordinary heat methods of evaporation destroy the effectiveness of penicillin, reduction of a purified solution of the drug to powder dryness for preserving and shipping has been a time-consuming process achieved by the conventional method in which the solution is caused to evaporate in a high vacuum at below-freezing temperatures.

As the first step in the all-electronic system, the engineers built the bulk-reducer which employs radio-frequency current to concentrate the penicillin solution to a constituency of 100,000 Oxford units per cubic centimeter. A standard RCA, 2,000-watt radio-frequency generator is connected to a setup consisting of three large glass bulbs joined in vertical series and attached to a

pump that maintains a relatively low vacuum. In this vacuum, the solution boils at 50 degrees Fahrenheit, a temperature unharmful to the drug during the brief period of exposure. Evaporation takes place at the rate of three liters an hour, some 48 times as fast as by conventional means.

Continuing the development, the RCA engineers built the electronic vacuum drier, an ingenious device of six porthole-frame vacuum chambers mounted on a round table and connected to a second RCA 2,000-watt generator. Vials containing 1 cc. of the concentrated penicillin are placed in the chambers and caused to rotate individually at 3,000 revolutions a minute, while being heated by radio-frequency current. In three minutes, the solution in the vials becomes a dry film.

To eliminate the small percentage of moisture that lingered in the dried penicillin, RCA engineers designed vacuum heating chambers, electrically heated units in which the vials are placed in moderate vacuum for 30 minutes. The system employs two units, each with sufficient capacity for completing the final drying process.

Each of the chambers in the electronic vacuum drier contains 34 vials of concentrated penicillin solution, and the system is so regulated that radio heat penetrates three of the vacuum chambers at one time, leaving the other three free for loading and unloading. An arrangement of red, green and amber lights at the side of each chamber informs the operator of progress.

The entire setup operates on push-button control and may be started or stopped at will without endangering the drug under process. In addition, it offers the great advantage of affording continuous production at a fixed rate of speed.

It was announced that development work is being continued to extend the application of the electronic drying process to many products, including other biologicals and pharmaceuticals, antitoxins, foods and granular chemicals. This work includes efforts to combine the use of electronic heating and freeze-drying methods so as to employ the advantages of both.

R. H. O.